Appendix D

Kinetic Energy Penetrator Environmental and Health Considerations

(Abridged)

Prepared for the

Kinetic Energy Penetrator Long Term Strategy Study

Submitted to:

U.S. Army Production Base Modernization Activity
Picatinny Arsenal, New Jersey 07806-5000

Submitted by:

Science Applications International Corporation
Paramus, NJ
Bothell, WA
Golden, CO
McLean, VA

July, 1990

Abridged for Non-Government Distribution

APPENDIX D

KINETIC ENERGY PENETRATORS
ENVIRONMENTAL AND HEALTH CONSIDERATIONS

Prepared for the
Kinetic Energy Penetrator Long Term Strategy Study

Volume 1
Summary Report

U.S. Army Production Base Modernization Activity
Picatinny Arsenal, New Jersey 07806-5000

July, 1990

VOLUME 1
TABLE OF CONTENTS

VOLUME 1
TABLE OF CONTENTS (Continued)

VOLUME 1
TABLE OF CONTENTS (Continued)

NOTE: Additional bibliographic references are contained in Volume 2.

ACGIH	- American Conference of Governmental Industrial Hygienists
AEHA	- Army Environmental Hygiene Agency
ALARA	- As Low As Reasonably Achievable
AMCCOM	- Armament, Munitions and Chemical Command
APE	- Ammunition Peculiar Equipment
APG	- Aberdeen Proving Ground
APT	- Ammonium Paratungstate
AR	- Army Regulation
ARDEC	- Armament Research, Development and Engineering Center
BEIR	- Biological Effects of Ionizing Radiation
BRL	- Ballistic Research Laboratory
CERCLA	- Comprehensive Environmental Response, Compensation, and Liability Act
CFR	- Code of Federal Regulations
CNS	- Central nervous system
CSTA	- Combat Systems Test Activity
D & D	- Decontamination and Decommissioning
DESCOM	- Depot Systems Command
DMWRs	- Depot Maintenance Work Requirements
DU	- Depleted Uranium
EPA	- Environmental Protection Agency
GFE	- Government Furnished Equipment
HEPA	- High Efficency Particulate Air
HF	- Hydrogen Fluoride
IPE	- Industrial Plant Equipment
JPG	- Jefferson Proving Ground
LAP	- Load, Assemble and Pack
LLW	- Low Level Waste
LSA	- Low Specific Activity
NEPA	- National Environmental Policy Act
NPDES	- National Pollutant Discharge Elimination System
NRC	- National Research Council - Nuclear Regulatory Commission
OSHA	- Occupational Safety and Health Administration

RCRA	- Resource Conservation and Recovery Act
RERF	- Radiation Effects Research Foundation
RI/FS	- Remedial Investigation/Feasibility Study
SEAD	- Seneca Army Depot
SOP	- Standard Operating Procedure
TECOM	- Test and Evaluation Command
TLV	- Threshold Limit Value
UF_4	- Uranium Tetrafluoride
UF_6	- Uranium Hexafluoride
UNSCEAR	- United Nations Scientific Committee on the Effects of Atomic Radiation
USADACS	- U.S. Army Defense Ammunition Center and School
USATHAMA	- U.S. Army Toxic and Hazardous Materials Agency
UXO	- Unexploded Ordnance
YPG	- Yuma Proving Ground

1.0 INTRODUCTION

The U.S. Army is currently formulating a strategy for future kinetic energy penetrating materials. This report addresses the environmental and health issues associated with depleted uranium (DU) and tungsten penetrators.

The objective of this study was to perform a preliminary assessment to investigate the environmental and health issues associated with DU and tungsten penetrator manufacturing, testing and recycle facilities. This work also included an assessment of requirements for decontamination of ammunition peculiar equipment (APE) and industrial plant equipment (IPE) at U.S. Army manufacturing sites. Combat issues were also addressed.

The work was executed as follows. A generic risk assessment was performed to provide an overall view of environmental and health issues at manufacturing, testing and recycle facilities. This task was performed by means of a literature search with subsequent evaluation of the data collected. In addition to the generic risk assessment, visits were made to a number of manufacturing, testing and recycle sites currently involved with DU and tungsten materials. Detailed technical interviews were conducted at each location with key personnel. Site visit reports were prepared and information obtained was incorporated into the generic risk assessment. Facilities visited are listed below:

Manufacturing Sites

Two DU manufacturers

One tungsten manufacturer

U.S. Army/Military Sites

Aberdeen Proving Ground/Edgewood Arsenal, MD

TECOM HQ (including Combat Systems Test Activity)

Ballistics Research Laboratory (BRL)

U.S. Army Toxic and Hazardous Materials Agency (USATHAMA)

U.S. Army Environmental Hygiene Agency (AEHA)

U.S. Army Military Sites (Cont'd)

AMCCOM HQ; Rock Island, IL

U.S. Army Defense Ammunition Center and School (USADACS)

DESCOM HQ; Chambersburg, PA

Eglin Air Force Base, FL

Jefferson Proving Ground; Madison, IN

Yuma Proving Ground; Yuma, AZ

This report summarizes information obtained during the study and presents findings and recommendations. Volume 2 contains the generic risk assessment report.

References throughout this report to DU and tungsten should be understood to mean the alloy materials unless otherwise stated.

1.1 BACKGROUND

The U.S. Army continues to produce and field kinetic energy penetrators composed of DU alloy materials. Due to the radioactive and chemically reactive nature of DU, concerns have arisen regarding environmental and health issues throughout the life cycle of the munition. DU penetrators have been produced since 1979, replacing tungsten penetrators which were used previously.

Concerns at manufacturing and testing facilities center on occupational and public exposures to DU along with potential contamination of the environment. Army mission requirements dictate that open range firing of penetrator munitions be conducted for quality assurance purposes, and the environmental impacts of this practice have been questioned.

Tungsten alloys are an alternative material for kinetic energy penetrators, and are currently being incorporated into various munitions. Only limited information to date has been prepared regarding the environmental and health effects of tungsten armaments. It has been previously assumed that tungsten penetrators present inconsequential environmental impacts.

This report addresses the above issues to enable informed decision making regarding the environmental and health impacts of utilizing each material. Additional tasks associated with the project include: identification of environmental issues associated with past practices; issues of regulatory concern; life cycle requirements; and cost estimating information. This environmental study will be incorporated into an overall U.S. Army investigation regarding kinetic energy penetrators.

This work effort was accomplished within an accelerated time frame to meet U.S. Army planning requirements. The bulk of the work, including site visits, was performed from September through November, 1989. Peer review of the draft report was performed by the U.S. Army and DU and tungsten manufacturers. This final report incorporates revisions arising out of peer review.

This document provides a relatively comprehensive view of current knowledge on the environmental/health effects of DU and tungsten. Other aspects of this report should be considered a preliminary assessment of the issues involved. Complete and comprehensive evaluation of U.S. Army penetrator related activities was not possible within the scope of this project. The work effort did not investigate issues associated with DU use in military items other than kinetic energy penetrators.

2.0 FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

2.1 OVERALL FINDINGS

We conclude that both DU and tungsten alloys are acceptable materials for use as kinetic energy penetrators with regard to human health and the environment. Human health risks are manageable to an acceptable level through proper industrial hygiene controls and monitoring, field practice and doctrine, and medical surveillance to ensure strict compliance to exposure levels promulgated by regulatory authorities. The environmental effects of both materials are low when appropriate controls are used. Tungsten munitions environmental effects have not been fully studied by the scientific community and should be further investigated.

Current management of DU manufacturing and testing facilities by private industry and the U.S. Army appears to be in accordance with procedures required by regulatory authorities. Approximately 9,450 acres at Aberdeen, Jefferson and Yuma Proving Grounds contain DU penetrators and penetrator fragments. Monitoring at these test facilities indicates that significant environmental impacts have not resulted from DU testing. However, there is a lack of knowledge regarding the consequences of open range testing. Range cleanups, if required, will be extremely complicated by the presence of unexploded ordnance (UXO). Reliable cost estimates for range cleanups are currently unavailable.

Major issues related to the penetrator life cycle are discussed throughout this chapter.

2.2 GENERIC RISK ASSESSMENT FINDINGS SYNOPSIS

Material Properties

DU: Heavy metal, radioactive (very low activity), highly reactive chemically, pyrophoric, undergoes significant oxidation and corrosion, alloyed with titanium or molybdenum.

Tungsten: Heavy metal, not radioactive, not highly reactive chemically, fine dust can present a fire or explosion hazard given an

ignition source, exhibits low corrosion although slight corrosion takes place in sea water; alloyed with nickel, cobalt or iron.

Comments: Excluding tungsten alloying elements, intrinsic properties of DU require increased safety precautions when compared with tungsten.

Material Uses

DU: Penetrators, ballasts and counterweights, and radiation shielding.

Tungsten: As carbides (cobalt alloy) in cutting and wear resistant materials, and welding and hard facing rods; mill products made from pure metal; alloy constituent; chemicals and compounds for nonmetallurgical applications.

Comments: Both materials have commercial applications.

Potential Health Hazards

DU: Low level alpha radiation emitter which is linked to cancer when exposures are internal, chemical toxicity causing kidney damage. Health hazards (i.e. uranium) have been extensively investigated.

Tungsten: Insoluble form: transient or permanent lung damage and skin irritation. Soluble form: systemic effects involving G.I. tract and central nervous system; also effects on fertility and developmental abnormalities in the musculoskeletal system. Proper assessment of the hazards of tungsten and compounds requires further scientific study. Alloyed with nickel (a suspected carcinogen) and cobalt (suspected to cause respiratory diseases). The finished alloyed material is considered to present significantly less potential health effects than the intermediate powder stage where nickel and cobalt are incorporated.

Comments: Both materials can be used safely. Also, there may be no driving force causing scientists to prioritize tungsten research.

Regulatory Issues

DU: Regulated by NRC with strict licensing requirements for material use. NRC requires exposures be kept "As Low As Reasonably Achievable" (ALARA) due to hypotheses that state: increased risk occurs from increased exposure; and any radiation exposure, no matter how small, presents some health risk. Also regulated by OSHA.

Tungsten: Regulated by OSHA. Has no equivalent licensing requirement to DU and regulatory controls are significantly less strict than for DU. Recommended airborne concentrations for tungsten and other materials have been set by the American Conference of Governmental Industrial Hygienists (ACGIH), a professional society, which uses the concept of threshold limit values (TLV). TLV implies that exposure below a certain threshold level will have no adverse effects, except for a small percentage of workers who may experience discomfort, and a smaller percentage of workers who may be affected by aggravation of a pre-existing condition or by development of an occupational illness.

Comments: Both materials are acceptable for use, as defined by regulations set by government agencies.

Production, Storage, Decontamination, Recycle

DU: Significant controls are required throughout production, storage, decontamination, recycle. Fires present the potential for health consequences and may require cleanup actions. Decontamination of manufacturing equipment is required. Low level waste (LLW) generated requires special burial.

Tungsten: Significant controls not required outside the powder metallurgy stage and other operations where dusts or aerosols are produced. Fire effects (while not inconsequential, with fire fighters recommended to wear self-contained breathing apparatus) are less severe. Decontamination of equipment is not a significant issue. Some compounds (and certain wastes from production operations) are recommended for disposal in a hazardous waste landfill.

Comments: There are fire risks associated with DU, primarily in manufacturing. These risks are considered manageable by regulatory agencies.

Range Testing

DU: Testing effects have been characterized and safety precautions are in place. Penetrators are fired against armor in enclosed targets with environmental controls. Soft target testing results in penetrators and fragments dispersed in the open environment on sites controlled by the military. There are no indications from environmental monitoring performed to date that soft target testing presents a significant environmental threat. It is likely, if not for environmental reasons, then for NRC license requirements and political concerns, that DU recovery from ranges will be required. However, UXO issues may make cleanups "impossible", and cleanups may not be necessary if ranges are perpetually controlled by the Army.

Tungsten: Testing effects have not been characterized and limited, if any, safety precautions are in place. Hard target testing health hazards to personnel are unknown and require study. It has been previously assumed, but not proven, that tungsten penetrators and fragments dispersed on open ranges will have negligible environmental effects.

Comments: DU recovery efforts can be anticipated unless precluded by UXO or other issues, while current requirements for retrieval of tungsten penetrators and fragments do not exist. Studies are required to determine the long-term environmental impacts from tungsten soft target range testing. The presumed lack of hazard from tungsten as expressed by nearly all test site personnel may mean appropriate health and safety measures are not being implemented.

Combat

DU: Exposures to military personnel may be greater than those allowed in peacetime, and could be locally significant on the battlefield. Cleanup of penetrators and fragments, as well as impact site decontamination may be required.

Tungsten: Potential exposures to respirable particles from penetrator impacts. Cleanup and decontamination is not likely to be required.

Comments: A difference in potential cleanup requirements is the significant finding from this comparison. Additional information on DU combat impacts will be needed for post-combat briefings and actions. A study is recommended.

Public Relations

DU: Public relations efforts are indicated, and may not be effective due to the public's perception of radioactivity. Fielding and combat activities present the potential for adverse international reaction.

Tungsten: Public relations efforts are not needed.

Comments: Increased costs can be expected for DU public relations when compared with tungsten.

2.2.1 Generic Risk Assessment Conclusions

Both DU and tungsten present low, acceptable risks for use in kinetic energy penetrators. The environmental and health risks of each material are manageable to an acceptable level, as defined by regulatory authorities, as long as appropriate controls are in place.

Tungsten use would provide significant advantages with regard to environmental and health matters. Less management controls are needed as tungsten is not radioactive (and is less chemically toxic than DU). Fire risks with associated environmental consequences are less for tungsten manufacturing sites when compared to DU. Public relations efforts are not needed for tungsten, but may be considerable with regard to DU fielding and combat use. Significant D & D of tungsten facilities is not required. Cleanup requirements on ranges and the battlefield, as well as combat exposures to soldiers, appear to favor tungsten, although these issues remain unsettled as discussed elsewhere in this report.

Evaluation of tungsten's advantages needs to incorporate two concepts. First, additional management actions are needed for DU over tungsten; however, when appropriate controls are used, the environmental and health effects of both materials are expected to be minimal and therefore roughly comparable. Secondly, although tungsten is generally not considered to be an industrial health hazard, there is a lack of definitive evidence regarding the health effects of tungsten.

2.3 MANUFACTURING SITES FINDINGS

* Production of DU (and tungsten) penetrators appears to be in accordance with applicable regulations and we have identified no unmanageable impacts to public health and the environment. Fires at DU manufacturing facilities could present a potential danger to nearby populations, involving cleanup costs and adverse public reaction. The probability of severe fires is low.

* Proposed regulatory changes by the NRC apparently will present no obstacles to continued DU production although uncertainty exists

regarding the effects of future regulations, including any impacts of the BEIR V report.

* Health physics programs at privately owned facilities apparently meet applicable standards, and in certain cases are very good.

Recommendations:

1. Investigate methods to decrease the risk and environmental consequences of DU manufacturing facility fires. Methods used in the plutonium industry may be applicable and technology transfer between industries should be investigated.

2. Ensure, through additional investigation and continued oversight, that future regulatory changes will not result in production problems with the DU manufacturing base.

3. Ensure, through periodic inspections, that health physics programs at contractor facilities meet and exceed applicable standards. Investigate the potential for governmental liability from contractor negligence in establishing worker background health data and continued medical surveillance.

2.4 RANGE FINDINGS

* Testing of DU penetrators currently takes place in accordance with applicable regulations and appears to present no significant danger to public health or the environment.

* Enclosed hard target testing is conducted in accordance with applicable regulations and with generally suitable environmental precautions.

* Significant site specific improvements can be made at each of the range facilities visited.

* Approximately 9,450 acres at Aberdeen, Jefferson and Yuma Proving Grounds have been used for penetrator testing and therefore contain scattered areas of DU materials. It appears that recovery of DU penetrators and fragments may eventually be required; however, additional soil cleanup measures may not be necessary assuming sites will not be released for uncontrolled use. Any range remedial actions are complicated by the unexploded ordnance issue, which may preclude cleanup actions. Cleanup costs cannot be currently estimated as the cleanup standard and appropriate remedial actions are unresolved issues.

* Factors that influence efforts toward penetrator recovery include possession limits of the site imposed by the NRC license.

* Tungsten contamination of ranges is not perceived in the testing community as an environmental concern, however there are no definitive scientific studies to verify or invalidate this conclusion.

Recommendations:

1. Detailed DU environmental studies regarding test range status are already in progress at most sites. Upon conclusion of these studies, strategies for remediation of the ranges should be developed, if necessary and feasible. Typical remedial investigational/feasibility study (RI/FS) procedures could be implemented. RI/FS work will need to address the UXO issue, and should address other potential range contaminants.

2. Soft target range testing strategy should be further analyzed to minimize environmental impacts from continued testing. Consideration should be given to maximizing penetrator recovery by restricting testing to ranges without unexploded ordnance. Improvements can also be made to enclosed testing facilities.

3. Investigate environmental effects of tungsten range testing.

2.5 RECYCLE AND DECONTAMINATION FINDINGS

* Facilities and methods to implement recycle of munitions and decontamination of equipment are, at best, only at the concept stage of development. This presents concerns regarding optimal life cycle control of penetrators.

* Decontamination studies for APE and IPE with recommendations have been prepared by AMCCOM. Decisions have not been made for disposition of contaminated equipment currently in storage.

* Decontamination and decommissioning (D & D) issues for manufacturing facilities and ranges have not been adequately addressed. D & D plans will be required by the NRC. Privately owned facilities will be required to implement legally binding financial agreements providing funds for D & D.

* Government closure estimates for manufacturing facilities are available. As low level waste (LLW) burial costs are in a state of flux and rising rapidly, estimates are subject to change.

* Closure costs for tungsten penetrator facilities could conceivably be incurred for remediation of heavy metal and possibly other contamination.

Recommendations:

1. Demilitarization of DU penetrators including recycling of material should be investigated.

2. Existing tungsten munition stockpiles should be recycled during demilitarization.

3. DU contaminated equipment in storage should be further addressed.

4. D & D issues should be investigated, including periodic evaluation of

- the need for a dedicated Army decontamination site.

2.6 LOW LEVEL WASTE FINDINGS

* Changes in Army radioactive waste disposal management will occur as a result of the Low Level Waste Act Policy Amendments of 1985 which establishes compacts and regional disposal sites. Ramifications of this law remain uncertain.

* Facilities will face large increases in radioactive waste management costs in the future. Available space for burial may be limited.

* Pyrophoricity of DU waste with potential accidental fires remains a concern. Methods to resolve this issue have been proposed.

* Waste minimization and volume reduction technologies are available but are not being fully implemented at Army owned facilities.

Recommendations

1. Ensure that suitable DU waste disposal plans with regard to the Low Level Waste Act Policy Amendments of 1985 are in place.

2. Investigate and implement technologies for waste minimization, volume reduction and recycle; and reducing pyrophoricity of wastes.

2.7 OTHER FINDINGS

* It is anticipated that outside regulatory agencies will become more involved in Army kinetic energy penetrator issues.

* Areas for further scientific research have been identified and are discussed in this report.

* We conclude that the Army kinetic energy penetrator program has generally been managed properly. However, there is room for significant improvement (as shown by issues discussed throughout this report) to minimize any adverse impact on the Army's primary mission requirement.

Recommendations:

1. Implement actions to address both outside agency issues and research and development needs.

2. Consider establishing a centralized kinetic energy penetrator office to provide life cycle management of these munitions.

3.0 DESCRIPTION OF FACILITIES IN THE INDUSTRY

3.1 ARMY MANAGEMENT ROLE

Army activities related to kinetic energy penetrators are primarily located in three major subordinate commands which report to the Army Materiel Command. These are the Armament, Munitions and Chemical Command (AMCCOM), the Test and Evaluation Command (TECOM), and the Depot Systems Command (DESCOM).

AMCCOM conducts research, development, engineering, procurement and materiel readiness functions for: conventional and nuclear weapons; ammunition; fire control systems; chemical warfare and chemical/biological defensive systems; ammunition peculiar equipment; test measurement and diagnostic equipment; and tools and maintenance equipment.

TECOM is responsible for test and evaluation of many types of Army materiel and has headquarters located at Aberdeen Proving Ground (APG) in Aberdeen, MD. Other agencies at APG and Edgewood Arsenal associated with penetrators are Combat Systems Test Activity (CSTA), part of TECOM; Ballistic Research Laboratory (BRL), U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), and the U.S. Army Environmental Hygiene Agency (AEHA). CSTA and BRL perform testing on munitions at APG under field and laboratory conditions. USATHAMA and AEHA perform oversight roles for environmental and health concerns at Army facilities nationwide, but do not conduct any penetrator operations. TECOM also manages several installations besides APG where testing is conducted, and two of these, Jefferson Proving Ground (JPG) in Madison, IN, and Yuma Proving Ground (YPG) in Yuma, AZ, conduct open-range test firing of penetrator ammunition.

The primary function of DESCOM is to manage the Army stockpile and its activities include storage, surveillance, maintenance, repair and renovation, demilitarization and recycle of many types of Army materiel ranging from small to large caliber ammunition, weapon systems, vehicles, communications and electronic instrumentation, and chemical warfare munitions and protective systems.

The management of APE and IPE required for manufacture of DU munitions is the responsibility of AMCCOM including the cleaning, renovation, and recycle of this equipment. Government furnished equipment (GFE) is present at both of the privately owned DU manufacturing sites visited during this study.

3.2 PRODUCTION OPERATIONS

3.2.1 DU

Two DU penetrator production sites were visited during this study. Manufacturing processes were observed and investigated. Due to the proprietary nature of some of these processes, manufacturing descriptions are not included in this report.

3.2.2 Tungsten

One tungsten production site was visited during this study. Manufacturing processes were observed and investigated. Due to the proprietary nature of some of these processes, manufacturing descriptions are not included in this report.

3.3 TESTING OPERATIONS

Current testing operations involve firing a variety of DU penetrators from standard Army weapons into both hard and soft targets. Past operations also involved firing tungsten penetrators into these same types of targets.

Hard target testing involves firing DU penetrators into armor plate to demonstrate penetrability. After penetrating armor plate, the penetrator fragments and portions of it burn forming uranium oxides. The degree of fragmentation and size of particles generated depends on firing conditions and target characteristics. In the past some hard target testing involving both DU and tungsten penetrators was done in open air. For the last several years, all DU penetrator hard target testing within DOD has been done in containment facilities. The containment facilities are concrete structures with a small opening through which the penetrator is fired. The containment facilities include an angled plate to stop penetrators which have gone through a target. All exhaust air from the containment facilities is filtered through high

efficiency particulate air (HEPA) filters resulting in a negligible release of DU contaminants to the environment.

In order to satisfy congressionally mandated live fire/lethality tests of weapons systems, a target enclosure to withstand the equivalent of 100 pounds of TNT explosive is being constructed on the Ford's Farm range of Aberdeen Proving Ground, Maryland. This enclosure identified as the Depleted Uranium Containment Fixture has been nicknamed the "Superbox". Scheduled to become operational in mid-1990, the Superbox will allow for the environmentally safe and effective testing of DU materials including firing DU penetrators into full sized, fully loaded armor vehicle targets. As in the small containment facilities for firing penetrators against armor plate, all exhaust air from the Superbox will be filtered through a series of HEPA filters.

Soft target testing involves firing DU penetrators through a target, usually located either 1000 or 4000 meters downrange, to measure flight accuracy. The target is normally canvas stretched between wood or metal poles. After passing through the target, the penetrator impacts the ground and is either stopped by a berm made of soil or is allowed to skip along the ground until it comes to rest further downrange. At the point where the penetrators impact the ground a trench develops. Continued firing of penetrators has resulted in trenches measuring as much as 600 meters long by 10 meters wide by 1 meter deep. Fragmentation of the penetrators during soft target testing is dependent on the type of soil and obstructions in the penetrator impact areas. Severe fragmentation can occur in those impact areas where soils are hard and rocky and where there are obstructions such as trees. Conversely, where the soils are very soft and where there are no obstructions, very little fragmentation occurs.

DU penetrator recovery programs differed greatly between the installations visited. Recovery rates varied from a low of approximately 5% to a high of near 56%. Factors influencing recovery rates include but are not limited to terrain, vegetative cover, unexploded ordnance on the range and the degree of fragmentation of the penetrators.

Very little information is available concerning the testing of tungsten penetrators. Personnel at the testing facilities consider tungsten as non-hazardous and treat it as such. Therefore, no records are readily available indicating the number or location of tungsten penetrators that were fired. Tungsten penetrators were visible on the surface of the ground on firing ranges visited.

It is known that tungsten penetrators have been fired into hard targets at some installations. No attempts were made to determine the aerosolization or fragmentation of the tungsten penetrator that occurred during these tests. Recent unpublished work by Battelle Pacific Northwest Laboratories indicates that tungsten hard target testing generates the same amount of airborne particles as DU, although particle size comparison data has not been compiled as of this date. There are unconfirmed reports that USATHAMA or AEHA has conducted tungsten hard target firing tests which indicated no exposure of personnel to airborne tungsten.

3.4 STORAGE, RECYCLE, DECONTAMINATION AND DISPOSAL ACTIVITIES

Five DESCOM depots hold NRC licenses for storage of DU ammunition: Letterkenny, Savanna, Seneca, Sierra, and Tooele. Savanna and Tooele are also licensed for recycle (demilitarization) of DU munitions. Active AMCCOM installations licensed for DU operations are: Lake City Army Ammunition Plant (firing range contamination); McAlester Army Ammunition Plant (DU contaminated equipment in storage); Iowa Army Ammunition Plant (load, assemble and pack); and Milan Army Ammunition Plant (load, assemble and pack; and demilitarization).

3.4.1 Storage and Transportation of DU Munitions

The AMCCOM Safety Office holds NRC license SUC 1380 which covers worldwide fielding of DU ammunition. This includes procurement, distribution and storage of ammunition, but does not cover manufacturing or demilitarization. NRC licenses are obtained by individual installations for the DU operations in which they are engaged.

Worker protection in AMCCOM facilities handling DU include use of film badges and ring badges, annual medical examinations, urinalysis, and annual refresher safety training. Each installation develops safety regulations covering their specific operations.

Health and Safety plans are specified in the NRC license for each installation. Safety data sheets are available at the DESCOM DU storage areas, and medical surveillance is performed for employees who work with DU ammunition. Periodic monitoring of the storage areas includes visual inspection of stored material, wipe tests and areal radiation surveys.

DU penetrator rods are transported as low level radiation hazard materials, but when they are part of a round of ammunition they are manifested as explosives. The shipping documents carried by the transporter identify the presence of radioactive material but this does not have to be shown on the outer surface of the vehicle. A letter of exemption for the shipping of DU materials (DOT-E-9649) provided to the Department of Defense by the Department of Transportation specifies that packaging and safety controls during transportation shall be appropriate to the explosive hazard of the product.

DU accident response guidance is provided in an Army Technical Bulletin TB-9-1300-278, "Guidelines for Safe Response to Handling, Storage, and Transportation Accidents Involving Army Tank Munitions Which Contain Depleted Uranium", 20 November 1987. This technical bulletin provides general information about DU, fire fighting procedures, guidelines for the types of accidents that may occur with DU including tank fires, identification of specially trained personnel for explosive ordnance and radiation protection, and decontamination procedures.

3.4.2 Recycling

Requirements for recycling (demilitarization) of DU ammunition are beginning to develop and can be expected to increase due to weapon system upgrades and normal deterioration. This requirement would increase if DU

ammunition were withdrawn from the inventory. The facilities needed for demilitarization of DU ammunition have not been developed.

The Armament Research, Development and Engineering Center (ARDEC) may currently be involved in developing DU recycling procedures and evaluating the cost of recycling alternatives. The Maintenance Management Division in the AMCCOM Defense Ammunition Directorate has been asked to find ways to minimize waste generation in DU recycling procedures.

Milan Army Ammunition Plant is reported to be capable of performing the DU demilitarization procedures specified in the Depot Maintenance Work Requirement (DMWRs) for 105mm and 120mm ammunition. Whether these procedures would be adequate to attain safety and environmental requirements is questionable. Demilitarization of these rounds would be in two steps. First, the cartridge cases would be removed and then the projectile containing the DU penetrator would by recycled/demilitarized.

The Logistics Engineering Office of the U.S. Army Defense Ammunition Center and School (USADACS) at Savanna, IL is currently conducting tests of a machine to extract DU cores from GAU-8 30 mm rounds, and is conducting a comprehensive study of demilitarization technology to replace open burning/open detonation. However, they are not developing DU ammunition demilitarization procedures.

DESCOM HQ staff were not aware of any facility with the necessary capabilities to demilitarize DU ammunition in accordance with applicable regulations. The Ammunition Equipment Directorate at Tooele Army Depot has prepared a concept document for DU munitions demilitarization.

3.4.3 Decontamination and DU Waste Disposal

Decontamination of APE and IPE has been studied by AMCCOM. It was concluded that Seneca Army Depot (SEAD) would be the preferred location for a future dedicated cleaning site for equipment but that the facility should not be constructed at this time due to the limited number of equipment items requiring

cleaning, and the need to assess the economics of equipment recycling at the end of the penetrator production program.

Another study commissioned by AMCCOM reviewed disposition alternatives for DU contaminated manufacturing equipment. The report concluded: the bulk of the material (primarily IPE) will not be useful elsewhere; because of rising burial costs it is imperative to quickly bury those items to be buried; compaction and supercompaction of items is useful; high pressure water lancing appears to be the preferred cleaning method; disposition choices were made for items at private sites as well as items stored at McAlester AAP.

Decontamination of test firing ranges is a more complex problem due to the large volumes of soil or target structures in which the DU and uranium oxides may be dispersed, and the presence of unexploded ordnance (UXO). Major volume reductions by DU waste concentration procedures will be required to control the cost of disposal operations. There is a substantial body of technology that could be adapted for DU waste cleanup; from uranium mining operations, drinking water treatment and nuclear facility decommissioning. However, development efforts will be required to select and adapt suitable decontamination technology to meet site-specific requirements.

Disposal of DU wastes requires the availability of low-level radioactive waste facilities. This requirement currently is being met through use of the Barnwell, SC facility, which may not be available after 1 January, 1993 for wastes generated outside the regional compact area. Costs for radioactive waste disposal are approaching $\$100/ft^3$ and are increasing. The Army has set up a waste consolidation facility at a site adjacent to the Barnwell low level radioactive waste disposal facility. It is a contractor owned, DOD dedicated facility for consolidating the radioactive components of the waste to minimize the total volume requiring landfill disposal. AMCCOM has the mission responsibility for Army low level radioactive waste disposal.

4.0 GENERIC RISK ASSESSMENT PRESENTATION

4.1 INTRODUCTION

Section 2.2 presents the generic risk assessment findings and conclusions in abbreviated form. This chapter will provide a discussion of that synopsis. Additional factual information is presented in an appendix to this chapter.

The generic risk assessment findings in this summary report were based upon information gathered throughout our study, in addition to the report contained in Volume 2.

4.2 BEIR V

After submission of our draft report, the National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR) presented the BEIR V report. Conclusions reached in our draft report (especially Volume 2) were prepared using similar state-of-the art knowledge available to the BEIR V panel including the Radiation Effects Research Foundation (RERF) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 1988 reports.

It is the opinion of experts in the areas of risk assessment, radiation biology, and health physics that there may be no reason to change risk estimates currently accepted by the health physics community (and used in our draft report) to incorporate recommendations of the BEIR V committee. Given the uncertainties inherent in risk assessments, technical experts generally agree that there is little real difference in current authoritative estimates of risk, including BEIR V. Additional information on the BEIR V report is presented in Volume 2.

4.3 ADVANTAGES TO TUNGSTEN USE

The synopsis presented in Chapter 2 concludes that tungsten use would have advantages over DU with regard to environmental matters. This section discusses those advantages and provides information regarding their significance.

4.3.1 Intrinsic Material Advantages

The material properties of DU; namely radioactivity (very low activity), pyrophoricity, and high chemical reactivity; require that increased safety precautions be implemented over those needed for tungsten.

Airborne concentration TLV values have been established for DU, tungsten, and tungsten alloying elements. (Actual TLV values for chemical toxicity of these materials are presented in the Chapter 4 appendix.) Significantly lower limits have been set for DU in comparison to tungsten. The insoluble form TLV for DU is 25 times lower than that of insoluble tungsten. This indicates a higher intrinsic material toxicity for DU. It is interesting to note that the 1989 proposed ACGIH TLV for nickel (a tungsten penetrator alloying element) is 4 times lower than that for DU.

Based on the above information, and given a hypothetical production item where the material performance characteristics of both DU and tungsten were identical, the scientific consensus would be to utilize tungsten. It is standard environmental practice to attempt to reduce the toxicity of a product or process through material substitution. However, environmental considerations form only one component of material substitution decisions.

The potential level of hazard presented by DU may be roughly compared to that of nickel or mercury. It is wrong to equate DU with much more hazardous materials such as plutonium or high level nuclear waste. Therefore, while safe use of DU requires appropriate health physics and other controls, extraordinary management measures are not required. Tungsten is generally considered to pose less health risks than other heavy metals such as mercury and cadmium.

4.3.2 Other Tungsten Advantages

Tungsten use presents a number of environmental advantages when compared with DU. The magnitude and significance of these advantages is open to subjective interpretation when balanced against differing material performance properties and other factors. This section presents information upon which subjective interpretations can be made.

DU requires controls throughout the entire life cycle. Controls consist of record keeping, medical evaluations, radiation monitoring of surfaces in contact with DU, breathing zone monitoring for airborne particles, ventilation requirements, etc. In comparison, strict controls are only needed during the tungsten powder metallurgy stage (and possibly some other areas of the life cycle where dusts and aerosols are generated). This issue was presented in Section 4.3.1 with regard to the increased potential risks associated with DU. It is also included here to highlight the increased costs and administrative requirements associated with DU use.

As controls in the work place cannot be perfectly implemented at all times, this may present additional advantages to tungsten use. Concerns also exist with specific workers and supervisors that regard DU (especially) and tungsten as "safe" materials and therefore are lax regarding personal health and safety.

Fires involving DU (and other radioactive substances) can have more severe environmental consequences than tungsten fires. There is a presumed low probability of a severe DU manufacturing site fire, and governmental agencies have determined that this level of risk is manageable.

Tungsten presents advantages in that public relations efforts are not required. DU public relations efforts can be mounted successfully given current information. Although litigation has not been an issue to date, there may be more litigation risks associated with DU than with tungsten.

4.3.3 Range Cleanup Requirements

There is presently uncertainty regarding future requirements for firing range cleanups on sites contaminated with DU penetrators. RI/FS work in progress by USATHAMA is expected to address this complicated issue, including problems posed by UXO. The properties of DU, including its breakdown through oxidation in the environment; coupled with regulatory and political issues, makes it likely that DU retrieval and/or cleanup of the ranges will be required, assuming UXO problems can be resolved. However, perpetual control of range sites by the Army

could influence cleanup requirements. Extensive DU environmental cleanups will probably not be required on newly established sites given prompt retrieval of penetrators and fragments and improved range testing/maintenance strategies.

A preliminary report has been prepared by Dr. John Till of Radiological Assessments Corporation comparing postulated DU and tungsten environmental health risks from uncontrolled releases to the environment. This study has implications regarding range (and battlefield) cleanup requirements. (See Appendix B).

Briefly summarized, Dr. Till's study concludes that due to bioaccumulation and bioconversion factors, risks to the public associated with ranges (and battlefields) contaminated with either DU or tungsten are roughly equivalent. It also implies that serious consideration be given to cleanup of lands contaminated with either of these heavy metals. These conclusions were reached utilizing a model developed by the consultant (in conjunction with a Department of Energy contract for Oak Ridge National Laboratory). The model assumes that over a 100 year time period, tungsten penetrators will undergo weathering with release of tungsten to environmental pathways. It is interesting to note that the model identifies little or no problem in groundwater or respirable air with postulated range or battlefield concentrations of either DU or tungsten. Health risks to the public may arise, however, due to ingestion of elevated levels of these heavy metals in meat and vegetables produced on the site. (The author recognizes the difference in corrosion rates between DU and tungsten, and states DU may pose a problem in a much shorter period of time than would tungsten.)

Dr. Till's study raises interesting points. Given this study's reasoning and the known dangers of the heavy metal class, it is conceivable that tungsten range cleanups may be required in the future. This study's conclusion is in accordance with the basic environmental science principle that uncontrolled release of potentially hazardous materials to the environment is not good public health practice. The report carries implications for materials other than DU and tungsten on the test ranges.

Tungsten and DU can possibly react differently in the environment and the food web to result in roughly comparable consequences. Yet, the increased toxicity and radioactivity of DU lead us to intuitively believe that it is of more concern in an uncontrolled release. We believe that future scientific pressures for cleanup of DU may be greater than those expressed for tungsten. Regulatory standards currently exist for acceptable levels of radioactivity in soil to protect public health. We are not aware of any environmental cleanup standards for tungsten regarding soil concentrations.

4.3.4 Combat

Our conclusions regarding the health and environmental acceptability of DU penetrators assume both controlled use and the presence of excellent health physics management practices. Combat conditions will lead to the uncontrolled release of DU. Individuals consulted have generally responded to this issue by saying it is irrelevant, or insignificant compared to the other risks of combat. However, environmental issues will arise if DU is used in combat. This issue also has relevance regarding the choice of penetrator material based upon its combat impacts, as well as funding levels for R&D to improve ballistic performance.

We reiterate our recommendation that studies of combat health and environmental impacts be performed. It is our initial hypothesis that impacts to civilian populations will not be significant from combat use, including post-combat impacts. However, aerosol DU exposures to soldiers on the battlefield could be significant with potential radiological and toxicological effects. These health impacts may be impossible to reliably quantify even with additional detailed studies. It is not our intention to overstate this issue given other combat risks, nor to imply that the health of soldiers will definitely be compromised. We are simply highlighting the potential for levels of exposure to military personnel during combat that would be unacceptable during peacetime conditions.

Battelle is completing a study of aerosols produced by tungsten penetrator hard-target testing. This information will be useful in assessing health impacts

to personnel on ranges and the battlefield. We do not expect to see the same level of problems with tungsten when compared to those associated with the potential inhalation of radioactive DU alpha-emitting particles; however, toxicological and health concerns could be present from nickel (and tungsten) aerosols.

4.3.4.1 Post-combat Cleanup

Assuming U.S. regulatory standards and health physics practices are followed, it is likely some form of remedial action will be required in a DU post-combat environment. Remedial actions may consist of retrieval of penetrator fragments and decontamination of impact sites such as tanks, rocks, trees, buildings, etc. It is assumed that an extraordinary and cost exorbitant cleanup would not be required, however further study is recommended.

Given the slow oxidation/corrosion of tungsten and the absence of radioactivity, it is unlikely that the U.S. military would face pressure for post-combat cleanup of tungsten alloy penetrators. Issues could conceivably arise due to short-term nickel and long-term tungsten effects, but would not be on the same level of public concern as with DU.

4.3.5 Costs

Some of the issues discussed above result in a conclusion that costs to utilize DU are higher than those associated with tungsten. We have not evaluated this concept in detail, but provide the following modifying comments. There are considerable "sunk" costs already associated with DU. For example, radiation protection programs have already been established and future costs for DU are associated with the continued functioning of existing programs. Likewise, D & D costs for manufacturing facilities will be incurred even if DU production ceases. Range retrieval costs for DU may be relatively low provided penetrators are fired on dedicated ranges where UXO is not present; however, the costs to implement this new policy were not investigated. Combat cleanup costs may be reduced if UXO teams are already required at the combat site; however, decontamination as well as disposal costs for low level waste could be significant.

4.4 HEALTH EFFECTS

Both DU and tungsten present the potential for deleterious health effects. Proof of these health effects has been obtained from laboratory research and occupational studies where exposures were high in comparison to current occupational exposures. Regulatory limits are set at levels that will (in general) prevent these deleterious effects from occurring. The state of the art of chemical and radiological toxicology has not advanced to a point where the effects from low levels of exposure are precisely known. Therefore, hypotheses are utilized to regulate these materials based on scientific research including observations of worker exposure.

There has been and continues to be a growing awareness of the environmental effects of heavy metals. Uranium (and therefore DU) has been extensively studied, both radiologically and toxicologically. A consensus exists that further research on tungsten health effects is required. There apparently has been no driving force to cause prioritization of tungsten research, such as large numbers of occupational illness.

DU and tungsten have both been studied by regulatory agencies charged with societal protection. Guidelines and limits have been set at which both materials can be safely used. Our study has shown that both DU and tungsten use in kinetic energy penetrators can meet these guidelines and limits.

4.4.1 Need for Tungsten Research

The following excerpt is taken from the introduction of the definitive study entitled, "criteria for a recommended standard ... Occupational Exposure to Tungsten and Cemented Tungsten Carbide" prepared by the Center for Disease Control's National Institute for Occupational Safety and Health, dated 1977:

> "The major concern in occupational exposure to tungsten, tungsten compounds, or cemented tungsten carbide is the potential for transient or permanent pulmonary damage. Irritation of the skin and upper and lower respiratory tract has also been associated with inhalation of, or skin contact with, these materials and should be considered in any work practices program.

> There is little information now available on the toxic effects of tungsten on animals and man which is applicable to the setting of a standard for the industrial environment. Retrospective and prospective epidemiologic studies are needed to assess the potential occupational hazards from tungsten and its compounds. Also, the abilities of various tungsten compounds to irritate the skin and eyes need to be investigated. Additional short- and long-term inhalation studies on animals are necessary to assess the toxic effects of tungsten, particularly on the liver, kidneys, lungs, and central nervous system (CNS). Such studies should aim also to distinguish the effects of exposure to tungsten and its compounds from those produced by mixtures containing cobalt or nickel. Chronic studies are also needed to investigate the carcinogenic, mutagenic, and teratogenic potentials of tungsten."

Additional scientific studies to resolve these questions have not been performed since publication of the 1977 report.

The significance of the NIOSH statements should neither be overblown or understated. To infer from these statements and other scientific evidence that significant problems may exist with tungsten appears to be an overreaction. There is scientific evidence that generally points to the safe use of tungsten. However, definitive scientific work on this matter has not been completed, including the effects of tungsten alone versus its alloys. Like many other industrial materials, tungsten presents health risks which need to be controlled for worker protection. Heavy metals in the environment are generally considered a serious issue by environmental professionals.

Additional knowledge is also needed on the health effects of (depleted) uranium, especially the precise effects of low level radiation risks. Uranium, in contrast to tungsten, has been extensively studied due to its role in the nuclear fuel cycle.

4.4.2 Quantitative Risk Assessments

The generic risk assessment presented in Volume 2 calculates the risk from DU manufacturing sites based upon an assumed average worker exposure of 5 to 10% of current NRC limits. The risk in fatalities per person is 0 to 2.5 x 10^{-3}. For an average sized DU manufacturing work force of 260 manufacturing workers

working for 20 years, this calculates to a maximum fatality rate of 0.65 persons per facility.

A quantitative risk assessment was not performed for tungsten manufacturing facilities. While the maximum calculated risk is likely to be lower than 2.5 x 10^{-3} fatalities per person, it would not be zero.

4.5 ENVIRONMENTAL PATHWAYS AND RECEPTORS

Similar environmental pathways and receptors exist for DU and tungsten introduced into the natural environment. DU penetrators (in the short-term) will undergo significantly more oxidation than tungsten penetrators, presenting the potential for increased amounts of material to enter pathways and affect receptors. Monitoring at test range sites to date indicates impacts of DU on various receptors has been minimal. Similar monitoring has not been conducted to date for tungsten dispersed on these ranges due to the presumption that impacts are negligible.

Risks to receptors from both materials appear to be minimal when proper controls are utilized.

4.6 PREVIOUS STUDIES

Excluding our work, there have been (at least) three major scientific studies performed on the environmental impacts of DU penetrator munitions. These studies were performed by: 1) the Joint Technical Coordinating Group for Munitions Effectiveness, Ad Hoc Working Group for Depleted Uranium, 1974, 2) the U.S. Army Pierre Committee, 1978, 3) the National Materials Advisory Board of the National Research Council, National Academy of Sciences, 1979. Each report, including our own, comes to the same basic conclusions on the acceptability of DU use in kinetic energy penetrators.

The only environmental study we are aware of regarding tungsten penetrators is the National Materials Advisory Board study discussed above. This report is more adamant than ours in concluding that no adverse impacts will result from

tungsten use. The report states that during impact of tungsten penetrators "it is inconceivable that concentrations would be reached and maintained so as to endanger animal life." It also states that the "danger from solubilization (of tungsten) in natural environments is negligible." Finally the report states, "There is no recognized reason to suspect that employment of tungsten alloy penetrators will result in a short- or long-range deleterious effect on the natural environment." We agree with this last statement, but caution that appropriate management practices may be needed to control potential impacts.

4.6.1 Additional DU Studies

Numerous studies have been performed on aerosols generated by DU hard target firing as well as "cook-off" tests simulating fires involving DU munitions. (Other studies have been performed and are in progress regarding DU materials scattered on the test ranges and their environmental impacts.) Our preliminary review of the literature indicates that environmental effects from either hard-target firing or munitions fires are relatively localized and do not present hazards outside the immediate area.

4.7 RISK CHARACTERIZATION

Both DU and tungsten present low, acceptable risks for use as kinetic energy penetrators. There are fundamental differences between chemical and radiological toxicity and methodologies used to interpret associated risks. To achieve minimal health, environmental, and political impacts, additional management actions are required for DU compared with tungsten. Fire risks, combat, and public relations are the major areas where DU management actions have inherent limitations. Environmental considerations need to be balanced against the mission performance of each material and other factors.

There are advantages to tungsten use regarding environmental and health matters as explained throughout this chapter and summarized in Section 2.2.1.

CHAPTER 4 APPENDIX

Section 2.2 presents the generic risk assessment findings in abbreviated form; therefore, issues pertinent to fuller understanding of the risk assessment were omitted. Some of these issues are presented below, with other information included in the generic risk assessment report contained in Volume 2. Similar headings to those presented in Section 2.2 are used below.

Material Properties

DU: DU is a byproduct of the uranium enrichment process, where natural uranium is enriched in the ^{235}U isotope. The byproduct from this process is uranium from which most of the ^{235}U isotope has been removed, i.e. depleted uranium. The uranium enrichment gaseous diffusion process produces a high purity ^{238}U, depleted of other isotopes and radioactive daughters.

Natural uranium and DU have essentially the same metallic properties, and are strong reducing agents. Uranium, especially if finely divided, is moisture-reactive in the presence of water or humidity, and will also decompose hydrated minerals such as cement or plaster; the hazards created are fire/explosion and pressure buildup. The half life of ^{238}U is 4.51×10^9 years, making it a very low activity radioactive material.

Tungsten: Tungsten alloy is stable in air. Actual corrosion rates for tungsten penetrators are available from testing performed on U. S. Navy Phalanx munitions.

Material Uses

DU: Total U.S. industrial demand in 1979 was 2,500 short tons, with 1,790 tons used for military ammunition. Information provided by a DU manufacturer indicates that commercial use has remained relatively constant for the 1979-1989 time period. DU counterweights are currently in service on Boeing 747 and McDonnell

Douglas L1011 and DC 10 aircraft, as well as some military aircraft. The Boeing 747 contains approximately 2500 pounds of DU. New aircraft are generally being constructed using materials other than DU as counterweights.

Tungsten: Total U.S. industrial demand in 1979 was 10,792 metric tons with 8,401 tons used in machinery. Total consumption of tungsten products in the U.S. in 1986 was 7,214 metric tons.

Health Hazards

DU: DU radiation presents a small external gamma radiation hazard. Health hazards occur primarily due to internal exposures. Soluble forms present chemical hazards primarily to the kidneys; while insoluble forms present hazards to the lungs from ionizing radiation, with particle size being an important factor. Radiation affects biological tissue by producing ionization and excitation of the atoms within the cells. Short term effects of high doses can result in death, while long term effects of low doses have been implicated in cancer. The current hypothesis being used for regulatory purposes is the "linear, non-threshold hypothesis" which states that the probability of cancer induction is directly and linearly related to the dose received, but there is no dose so low that the probability of effect is zero.

Tungsten: Most tungsten studies have dealt with the effects of mixed dusts including cobalt.

DU and Tungsten: Environmental pathways and receptors for both materials are similar. Inhalation presents the greatest risk from both materials. Heavy metal movement in soils is low relative to other materials. The density of both materials results in prompt settling and less resuspension of particles when compared with other metals. Detailed

comparisons between the two materials need to compare particle generation and size during equivalent operations (further discussed in Volume 2).

Regulatory Issues:

DU: ACGIH TLV values (chemical):

	Soluble:	0.05 mg/m^3
	Insoluble:	0.2 mg/m^3 (0.25 mg/m^3 OSHA PEL)
Tungsten:	TLV Values:	
	Soluble:	1 mg/m^3
	Insoluble:	5 mg/m^3
*Nickel:		
	*Metal:	0.05 mg/m^3
	*Insoluble:	0.05 mg/m^3
	*Soluble:	0.05 mg/m^3
Cobalt:	TLV Value:	0.05 mg/m^3

*TLV values for nickel are from the Notice of Intended Changes (for 1989-90) from the ACGIH "Threshold Limit Values and Biological Exposure Indices for 1989-1990". (There has been controversy in the past regarding the carcinogenicity of nickel metal as opposed to its compounds such as nickel sulfide. Current ACGIH documents consider the metal to be carcinogenic.)

ACGIH recommends that even though serious injury is not believed likely as a result of exposure to the threshold limit concentrations, the best practice is to maintain concentrations of all atmospheric contaminants as low as is practical. For confirmed human carcinogens (such as nickel), worker exposure by all routes should be carefully controlled to levels as low as reasonably achievable (ALARA) below the TLV.

Production, Storage, Decon, Recycle

DU: The pyrophoric nature of DU inherently results in fire risks during certain operations, and also leads to increased particle generation through aerosolization under certain conditions. DU production requires handling of HF and UF_6.

Tungsten: Tungsten alloy production requires handling of nickel powder. Aerosol particles in the 0.5 to 1 micron range are abundant around powder metallurgy operations which utilize tungsten metal and tungsten carbide.

5.0 REGULATORY ISSUES

5.1 EXISTING RULES

There are a number of regulations that cover the manufacture, handling, transportation, use and disposal of depleted uranium. Most arise from the fact that depleted uranium is a source material, as defined by the Atomic Energy Act. This section is not intended to be a complete and comprehensive review of pertinent regulations.

The NRC regulates depleted uranium under a number of Parts of Title 10 of the Code of Federal Regulations (10 CFR). These include 10 CFR 19 (Notices, instructions and reports to workers), 20 (Standards for protection against radiation), 21 (Reporting of defects and noncompliance), 40 (Domestic licensing of source material), 51 (Environmental protection regulations...), and 71 (Packaging and transportation of radioactive material). 10 CFR 40 puts forth the actual licensing requirements that must be met to manufacture, keep and use a source material such as depleted uranium. In order to meet these regulations, each range testing site has an NRC license or permit drawn on a license. Regarding DU production sites, facilities are licensed by the NRC or the state in which they are located.

10 CFR 51 lists Nuclear Regulatory Commission federal regulations regarding its authority under the National Environmental Policy Act (NEPA). Numerous licensing and regulatory actions are eligible for a categorical exclusion from NEPA requirements since the Commission by rule or regulation has found "the category of actions does not individually or cumulatively have a significant effect on the human environment." 10 CFR 51.22(C)14(XV) gives a categorical exclusion to: "Possession, manufacturing, processing, shipment, testing, or other use of depleted uranium military munitions."

Other Federal regulations that are directly applicable to depleted uranium include Department of Transportation regulations in 49 CFR pertaining to the transportation of radioactive material (these are adopted by the Department of Defense by reference), Occupational Safety and Health Administration (OSHA)

regulations covering hazardous waste operations and emergency response for the health and safety of employees (29 CFR 1910.120) and Department of the Army regulations (AR) 40-14, 385-11, 385-112, 385-100 and Standard Operating Procedure (SOP) 385-312 which all apply to depleted uranium activities.

Army Regulation (AR) 700-64 provides policy for the control of radioactive commodities. It states in section 1-2, "Policy" that:

> "The use of radioactive materials in items of supply shall be kept to a minimum consistent with DOD needs. Practical nonradioactive substitutes shall be procured and used when feasible."

AR 700-64 requires life cycle controls, medical exams for personnel, and written emergency response plans.

Other pertinent Army regulations regarding materiel and environmental impacts are listed below:

> AR200-1: "2-4. Responsibilities .... Commanding General DARCOM will (1) Under the general staff supervision of the DCSRDA, develop, test, and acquire Army materiel; assure that this materiel minimizes the life-cycle environmental impacts of materiel without compromising mission effectiveness."

> AR200-2: "1-4 Policies. a. It is the continuing policy of DA, as a trustee of the environment, to carry out its mission of national security in a manner consistent with NEPA (National Environmental Policy Act) and other applicable environmental standards, laws, and policies. All practicable means consistent with other essential considerations of national policy should be employed to minimize or avoid adverse environmental consequences ..."

The manufacturing plants operate under National Pollutant Discharge Elimination System (NPDES) permits issued by state agencies in compliance with the Federal Water Pollution Control Act. The permits authorize discharge of process, domestic and cooling wastewaters into water bodies subject to limitations and monitoring requirements. The monitoring requirements include chemical and thermal content limits.

A number of other Environmental Protection Agency (EPA) regulations and statutes, while not directly applicable, may be either relevant or appropriate and should therefore be considered. The first of these is found in 40 CFR 192 which addresses health and environmental protection standards for uranium and thorium mill tailings and includes standards for inactive uranium processing sites and management of uranium byproduct materials. Less clear is the possible relevance of two major statutes that EPA is charged with enforcing, the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA - "Superfund").

RCRA should not directly affect any of the sites investigated; it may, however, affect some of the wastes produced at the manufacturing plants if they are determined to be "mixed" (both low-level radioactive and RCRA hazardous wastes). CERCLA/Superfund should not be an issue as it is currently not EPA policy to include "sites that result from contamination associated with facilities licensed by the NRC..." (48 FR 40661), as long as the contamination remains on-site.

State regulations and jurisdiction may also come into effect at some or all of the sites in question. In addition, regulations which apply to the destination points for the waste (Barnwell, Beatty and Richland burial sites) also impact on the industry. These regulations dictate the form the wastes must be in and how they must be packaged.

5.2 FUTURE REQUIREMENTS AND IMPACTS

There are a number of new or pending regulations which will affect the operation of the production and test facilities. The first is the newest version of the revisions to 10 CFR 20. There will be four major changes: (1) individual external exposures will go from 5 rem/year whole body, 75 rem/year extremities to 5 and 50 respectively; (2) internal whole body exposure limit of 5 or 15 for one organ will be limited to 5 rem/year; (3) total internal and external exposures will be limited to 5 rem/year; (4) concentration limit of uranium particles will be decreased. For the manufacturing sites visited during this study, the new regulations are not expected to be a problem as long as NRC and/or

the states allow consideration of particle size. Items (1), (2), and (3) above will need to be addressed by the test facilities.

The other major regulation change is in EPA regulations on release of radionuclides into the environment. Currently, the limit is set in 10 CFR 20 and is based on a maximum concentration of 5 X 10^{-12} μCi/ml. This is based on a maximum exposure of 500 mrem/year to people in unrestricted areas. The new EPA rule would be based on maximum exposure to nearby neighbors. The actual level of exposure has just been set at 10 mrem/year. Current releases by the DU manufacturers visited will meet this level. This new limit is under considerable controversy, and NRC points out that they generally accept exposures less than 10 mrem/year as low enough to require no regulation.

EPA criteria on residual radioactive contamination limits in soils are expected in 1992. The recently promulgated NRC "D and D" rule will require all facilities using licensed radioactive material to develop a decontamination and decommissioning plan which would be implemented at the end of the facilities useful life. Financial assurance mechanisms for funding this work will be required from private industry.

The tightened regulations from EPA on spill control and more stringent work practice rules from OSHA have required more controls and programs at the plants but these affect all industries, not just those handling radioactive materials.

5.3 LOW-LEVEL WASTE DISPOSAL ISSUES

Currently, Army low-level waste material that is generated by manufacturing, testing or recycling depleted uranium is disposed of primarily at the Barnwell, SC disposal facility. This arrangement may not be available after 1 January 1993. At that time, the final milestone set up by the Low-Level Waste Policy Act Amendments of 1985 may go into effect. Each State must then handle the low-level waste generated within its borders either at its own disposal facility or at the regional disposal facility if it belongs to a Congressionally-approved compact.

This will affect the Army by decentralizing the waste disposal organization that currently exists and by making the Army subject to as many as 13 different sets of regulations, should waste be generated in each of the compact regions.

A memorandum of understanding between the Departments of Defense and Energy was previously signed regarding LLW disposal contingency plans. Although this agreement has expired, it is expected to be renewed. The previous agreement stated that if DOD cannot utilize commercial disposal sites through no fault of its own, DOE disposal sites will be made available to DOD.

There are currently plans to license a low specific activity (LSA) facility in Utah to permit bulk disposal of certain regulated LLW.

Recycling of DU may also serve to reduce waste disposal demands.

5.4 TUNGSTEN

The previous portions of this chapter primarily discuss DU regulatory requirements, although certain regulations mentioned are also applicable to the tungsten industry.

Tungsten is regulated under OSHA's General Industry Standards. Therefore the tungsten industry is subject to similar controls applied to other industrial plants, including permissible exposure levels (PEL) for airborne contaminants. Other applicable requirements include: air pollution control system permitting; hazardous waste regulations; worker right-to-know; and National Pollutant Discharge Elimination System (NPDES) permitting.

6.0 ENVIRONMENTAL AND HEALTH ASSESSMENT OF FACILITIES

This section addresses the status of environmental health and safety as observed from the visits to specific sites and records provided by those sites. The sites visited are considered to be representative of operations in the penetrator industry. Information presented should be considered a preliminary assessment only.

6.1 PRODUCTION OPERATIONS

6.1.1 Depleted Uranium

Uranium is the contaminant of major concern in the DU manufacturing operations. Other hazardous materials and wastes used or generated include hydrogen fluoride (HF), barium chloride, magnesium fluoride, acids and halogenated solvents. The handling of these other materials is conventional and generally subservient to the necessary controls for radioactive materials. For example, the ventilation controls necessary for uranium containment provide necessary safeguards for HF. Therefore this section focuses on the risks associated with the depleted uranium.

6.1.1.1 Pathways

The principal pathway for release of depleted uranium from the production facilities is air contamination due to a fire or ventilation equipment misuse or failure. Airborne contamination in the plant is controlled by turning over large quantities of air through the ventilation system to carry away possible dust contamination. The air is filtered usually through roughing filters and then High Efficiency Particulate Air (HEPA) filters. The filter systems remove the contaminated dust allowing the air to exhaust to the environment. Air is drawn not only from the rooms but through many of the machine enclosures. The machining operations generate smoke and fine particles in addition to the chips. Since uranium (especially newly cut uranium) is pyrophoric, the dust presents a significant fire hazard. In addition uranium is highly reactive with water causing liberation of heat and flammable hydrogen. Therefore, water is not a useable fire fighting agent for duct fires. It may be very difficult to avoid

a release to the environment if a severe fire occurs. This is because fires in the ducts can not only destroy the filters but can also, under certain circumstances, load them with smoke particles beyond their capacity. Fires outside the ducts can also load filters to capacity. As a result the facilit have taken significant precautions against this problem. In short, there is currently no absolute safeguard. The measures taken are reasonable and certainly reduce the fire risk considerably. Nevertheless this is certainly the most difficult environmental problem at the DU manufacturing sites.

Another pathway for release is an accidental discharge of wastewater. A rupture in a pipe from an external impact or due to overpressuring the system could potentially allow uranium-contaminated wastewater to reach the soil and ground water underlying the facility. Wastewater could also flow through the surface drainage system of the facility until it reached nearby waterways.

A third potential pathway for contamination is through openings in the floors of production areas, either made intentionally for equipment installation and concrete expansion/contraction or from cracking of concrete slabs. Contaminant movement through such openings would lead to soil contamination and, potentially, ground water contamination.

6.1.1.2 Potential Receptors

Potential human and environmental receptors include air which would convey contamination to local residents and populations at local businesses or institutions. At the DU facilities visited during this study, there is a high density population area near one plant, and a public school downwind of the other plant. Other receptors include ground and surface water and users of ground and surface water, and soil and bedrock underlying the facility. In addition, building components and equipment in production and waste processing areas are or can become contaminated with DU.

The most significant receptors are the workers who are closely associated with the operations and handle the materials daily. Direct exposure to radiation and inhalation of respirable uranium particles would be of most concern.

6.1.1.3 Summary Assessment

The assessment of the production operations emphasizes four areas: (1) routine environmental effects; (2) environmental effects due to events; (3) worker health impacts from routine operations; (4) worker health impacts due to events. Of these four, it is our preliminary opinion that the first three are being handled well. Generally the approach to the fourth is also good but some possible improvements, such as more readily available emergency respiratory protection, might be made at certain sites. Limited examination of personnel and plant monitoring records indicates compliance with applicable standards.

Routine Environmental Effects

Large quantities of air are exhausted from plant stacks. These stacks ventilate work areas and process equipment. Of major importance is to maintain low levels of airborne contamination. The measures taken at the plant include high-efficiency filtration, continuous stack monitoring, continuous monitoring of work area atmospheres and plant periphery monitoring. The control and monitoring programs appear to be well conceived and administered. No significant environmental effect should result from routine stack exhaust. Manufacturing site releases are approximately 5% or less of the maximum allowable annual release.

Radioactive and non-radioactive contaminants could be released via routine discharge of process waste waters. The operation and control of the plant discharges under NPDES permitting and monitoring indicates that no significant environmental effects are likely. Data reviewed from discharge permit reports indicate that releases are well within the requirements of the permit.

The possibility of some soil contamination through intentional or accidental holes or cracks in the floor exist. It is difficult to gage the magnitude of such a problem. Significant soil contamination due to a floor crack was discovered at a penetrator manufacturing facility which is no longer operational. The impact of such contamination was relatively low since the material was relatively insoluble. The major impact was on cleanup of the plant during decommissioning, which was successfully performed at this facility.

Environmental Effects Due to Events

The largest concern in this category is airborne contamination release due to a significant fire within the plant. It is possible that filters would be destroyed by the fire thus allowing release of dust and smoke. There have been minor fire events which have resulted in reportable releases but which did not require any major response for public safety. Throughout the plants there are many devices and procedures designed to minimize the fire problem. While the situation is currently well handled, this is obviously an area to strive for improvement. Some techniques developed in defense plants producing plutonium may be applicable.

Of more minor concern is the possibility of a breach in process waste water piping resulting in a release of contamination on the ground and ultimately to the ground water. A major accident such as breach of piping from some accidental impact is very low probability.

Routine Worker Exposure

The radiation protection programs at the plants appear to be good based on limited observations. Worker exposures are generally small fractions of applicable limits. ALARA is practiced in all aspects of the program. The observations during the visits indicate a dedication to the program by all concerned. Review of personnel exposure data for various periods of time in 1988 and 1989 indicate values well below limits. It is not expected that any significant exposure problems will arise.

As a general practice, health physics programs at various sites should be closely monitored with regard to worker exposure.

Worker Exposure from Events

The only significant event to note here is again fire. In the case of workers the effect could be severe since they would be at the source and there could be little time to mitigate exposure. The devices and procedures in place to mitigate fire effects contribute to decreasing the probability of such an

event. Further investigation of safeguards would be worthwhile although the current risk appears to be manageable.

6.1.2 Tungsten

A key difference between tungsten and DU is that tungsten toxicity (or the toxicity of its alloying metals) is chemical as opposed to radiological. The tungsten industry is regulated under industrial safety (e.g. OSHA) and not under radioactive material regulations.

Only one tungsten manufacturing facility was visited during this study, with conditions noted assumed to be representative of other manufacturers.

6.1.2.1 Pathways

For tungsten or its alloying metals the only pathway currently considered in exposure concerns is airborne transport. Exposure of the lungs is the major concern. Soil contamination could be of concern if resuspension could occur thus resulting in the airborne pathway. Little is known about waterborne concerns except that there is growing awareness of heavy metals as an environmental hazard in water. Currently there would be greater concern about the nickel and other elements that are alloyed with the tungsten.

6.1.2.2 Potential Receptors

Potential receptors for a tungsten facility are the workers in the plant, soils, any nearby waterbodies, and the surrounding residential and business population. Clearly the receptors of immediate known concern are the workers in the plant who are exposed to an inhalation hazard.

6.1.2.3 Summary Assessment

Chemical Processing - The process of converting ore and scrap to APT takes place regardless of the presence of penetrator production. Current monitoring and controls are sufficient to minimize risk from routine exposure and environmental releases. This phase of operation provides some risk from events due to the presence of volatile and caustic chemicals present for processing. Also, the

wastewater processing plant may be subject to events which may precipitate accidental discharge. There are no large quantities of chemicals produced which cannot be treated and only the minimum quantities necessary for production are stored onsite which minimizes the chance of a significant release.

Kinetic Energy Penetrator Fabrication - Worker exposure to dust inhalation is minimized by the use of mechanical handling of powders and monitoring of work areas. Process dust and ore powders are unlikely to migrate offsite in any significant concentrations. Available information shows tungsten production to have relatively low environmental or health risks when manufacturing and recycling occur under the controlled conditions present at the plant which was visited.

In-plant air monitoring is conducted on a periodic basis. Personal (breathing zone) air samples are collected and compared to appropriate occupation exposure limits. Facility personnel stated that "measured and estimated airborne concentrations indicate that exposures during heavy-metal processing are within the current limits". Air contamination control consists of local exhaust ventilation terminating in bag house dust collectors. There is also some concern about skin contact with powders, and gloves may be worn to minimize skin contact. Other respiratory protection is not currently considered necessary but we were told that half-mask cartridge respirators are made available.

With the current knowledge of the hazards of tungsten production, there is no information which would lead to a conclusion of significant deleterious effects to the environment or human health.

6.2 ARMY OPERATIONS

This section discusses environmental health and safety issues associated with Army operations described in Section 3. A discussion of environmental pathways and receptors for testing operations is contained in Section 6.2.3 and Table 6-1 (located at the end of this chapter). Pathways and receptors for storage, decon and recycle facilities are assumed to be similar to testing operations and those discussed previously for production sites.

6.2.1 General Health and Safety Activities

DU penetrator operations throughout the Army appear to take place in accordance with NRC license requirements and generally acceptable health and safety practices. Overviews of some of these practices are discussed below.

Worker protection in AMCCOM facilities handling DU includes use of film badges, ring badges, annual medical examinations, urinalysis, and annual refresher safety training. Each installation develops safety regulations covering their specific operations. The Environmental Quality Division (EQD) at AMCCOM maintains an oversight program for environmental activities at all AMCCOM installations. The individual installations are responsible for their own environmental compliance programs, but the AMCCOM office monitors them and may provide support if needed. EQD maintains a central data base on environmental program activities and updates this data base quarterly. Data collected includes: operations, notices of deficiency and violation, media coverage, compliance costs particularly for large projects, interagency agreements, permits, Federal Facility Compliance Program, and USATHAMA RI/FS studies and work plans.

Health and Safety plans are specified in the NRC license for each DESCOM installation. Safety data sheets are available at the DU storage areas, and medical surveillance is performed for employees who work with DU ammunition. Periodic monitoring of the storage areas includes visual inspection of stored material, wipe tests and areal radiation surveys.

Because of the variety and often different types of testing being conducted at the TECOM installations, each installation develops its own health and safety plan. Training programs have been implemented to ensure personnel are advised of potential hazards and instructed concerning the proper use of protective equipment before working with DU penetrators. Health monitoring of workers as well as environmental monitoring of ranges are also conducted. It has been stated by individuals from Battelle Pacific Northwest Laboratories that gunners on ranges may need more health physics education.

AEHA maintains oversight of health aspects of DU operations on Army installations. This includes tracking NRC licenses on Army installations, providing radiation and health surveys, and conducting special studies.

The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) is charged with oversight on environmental compliance at Army installations. Support is provided in the form of environmental audits and assessments, remedial investigation/feasibility studies, quick-response assistance in the correction of notices of violation, development and application of technology for environmental monitoring and remediation, the development and application of waste minimization technology, and the management of environmental aspects of base closure. USATHAMA is currently conducting RI/FS activities at several installations where DU penetrators are being tested.

There are generally no concerns for tungsten environmental effects throughout Army facilities we visited, and therefore only limited, if any, health and safety precautions are taken.

6.2.2 Storage Operations

DESCOM is responsible for managing the Army stockpile including storage, decontamination, and recycle of DU penetrators and DU contaminated material.

DU accident response guidance is provided in an Army Technical Bulletin TB-9-1300-278 "Guidelines for Safe Response to Handling, Storage, and Transportation Accidents Involving Army Tank Munitions Which Contain Depleted Uranium", 20 November 1987. This technical bulletin provides general information about DU, firefighting procedures, guidelines for the types of accidents that may occur with DU including tank fires, information on specially trained personnel for explosive ordnance and radiation protection, and decontamination procedures.

Our DESCOM site visit indicated that the environmental hazards in DESCOM DU operations are recognized and controllable.

6.2.3 Testing Operations

TECOM conducts testing and evaluation of all types of Army materiel. Among the past and current operations conducted by TECOM are operations involving DU and tungsten penetrators.

The firing of DU penetrators into soft targets results in the release of DU fragments and particulates into the environment. The size of the DU fragments and particulates released largely determines the potential threat to personnel and the environment. The primary potential threat comes from the small respirable size particulates.

6.2.3.1 Pathways

There are several pathways for release of DU during the testing operations. Of principal concern is the airborne respirable size particulates generated when DU penetrators are fired into hard targets and when the penetrators strike rocks, trees, or other obstructions during soft target penetrator testing. Airborne contamination is currently being controlled during the hard target testing by filtering the exhaust air from the hard target containment facilities through HEPA filters. This virtually eliminates release of DU contamination to the environment where it might later become resuspended and pose a potential inhalation hazard to personnel working in areas close to the containment facilities. Contamination can leave enclosed test facilities when they are opened for entry by personnel and this issue should be investigated by the Army. Respirable size particulates could also be present in the DU penetrator impact area on the soft target testing ranges. Range operating procedures have been developed and implemented to protect personnel, and personnel entering and working in these areas are advised concerning the potential hazards and provided adequate protective equipment.

Fire or explosion in DU waste handling activities presents additional pathways for DU to be released to the environment. Airborne contamination generated by the fire or explosion as well as surface water runoff from fire fighting activities could reach public access areas or nearby waterways.

During penetrator recovery only complete penetrators or large fragments are normally recovered. Another pathway exists when the small fragments and uranium oxides that form on the outside of the penetrator could be carried into nearby waterways by surface water runoff and soil erosion. Groundwater contamination potential is also present.

Another possible pathway exists when small particles of DU are deposited on vegetation. Animals such as deer, rabbits, birds, etc. that feed on this vegetation are often hunted for food by man and other predators. Fruits, nuts, and berries that may become contaminated may also be harvested for human consumption. Air monitoring conducted during burning of vegetation on ranges indicates negligible environmental effects from air emissions.

6.2.3.2 Potential Receptors

DU penetrator testing facilities are located well away from population centers primarily due to safety distance requirements for explosives. Therefore, it is unlikely that airborne contamination could reach areas open to the general public. Air could become a potential human or environmental receptor upon resuspension of DU particles. Other potential receptors include ground and surface water, users of ground and surface water, and the food web.

6.2.4 Tungsten

The firing of tungsten penetrators into both hard and soft targets results in the release of tungsten fragments and fine particulates into the environment. Pathways and receptors are likely to be similar to those for DU.

6.2.5 Range Environmental Studies and Monitoring Programs

We have gathered information on environmental studies and monitoring at four range facilities. The Lake City Army Ammunition Plant operates a firing range which has DU contamination from previous operations. AEHA has performed studies on site and is now recommending groundwater monitoring. The general consensus of Lake City AAP government and contractor environmental personnel is that decontamination of the range is not recommended because there is no hazard

to on-site personnel, and cleanup of DU would not remove other more serious hazards (UXO).

A number of studies have been commissioned at Aberdeen Proving Ground (APG) to define the environmental and occupational impact of DU testing. The consensus findings appear to support limited aerosol distribution (within 400 m of the target under open air testing) and limited movement of DU contaminated sediment from the immediate vicinity of the target area. An Environmental Radiological Monitoring program was established in which air samples are taken weekly and quarterly samples are taken at 18 stations of vegetation, soil, sediment, water, and aquatic fauna. The samples are analyzed for gross alpha, gross beta, and total U when appropriate.

A number of environmental assessments are currently underway by various agencies. These are reportedly within six to twelve months (March to October 1990) of completion. Recent unpublished work indicates that APG soils retain DU, and that DU materials are not found below 6" from the surface.

Numerous studies have been conducted at Jefferson Proving Ground (JPG) to determine the environmental and health effects of testing DU penetrators. DU penetrator firing began in 1984. Prior to firing DU, a program was developed and implemented to sample soils, surface water, ground water, and stream sediments. Results of this initial study serve as a baseline for the current environmental monitoring program. Air sampling during burning of vegetation on the firing ranges and sampling of deer tissue have been added to the original sampling plan. The JPG program is considered the model for other TECOM installations to follow in developing their DU monitoring programs.

EG&G Mound Applied Technologies, Inc. completed a comprehensive review of the environmental program at JPG. Results of their review were contained in a report entitled "Review of the Radiological Environmental Monitoring Data at U.S. Army Jefferson Proving Ground, Madison, Indiana" dated July 1988.

Sampling results at JPG generally show only slight soil contamination, specifically in areas of penetrator impacts. Surface water, sediment,

groundwater, air sampling and deer tissue sampling has shown negligible amounts of DU present in these media.

Numerous studies have been conducted to determine the potential health and environmental effects of testing DU munitions at Yuma Proving Ground (YPG). Data from these studies has been utilized in developing and implementing a comprehensive air, soil, and surface water transport program to monitor the potential effects from soft target testing of DU penetrators. Because of the depth to groundwater and the low annual rainfall, contamination of groundwater has been determined to be so unlikely that groundwater monitoring is not performed. In a Memorandum for Record dated 10 October 1987, the radiation protection officer analyzed all data from the air, soil, and water transport sampling program for historical trends. His analysis indicated that there was no significant DU migration from the DU penetrator contaminated areas.

Monitoring programs should include sampling for DU and tungsten alloying elements (if not already being performed). Further investigation of this issue is warranted.

Based on the above studies, there appears to be no significant environmental threat at ranges used for DU penetrator testing. Institutional controls now in practice such as restricted access, monitoring, worker protection and training, should provide adequate health and environmental protection.

It appears likely that recovery of DU penetrators and fragments will be required at these ranges. Requirements for actual soil cleanups are uncertain, but will depend heavily on whether or not range sites remain under Army control indefinitely. Technologies to perform soil cleanups, if required, are available; however, further research and development may be required. Any remedial action will face the problem of UXO on the ranges.

6.2.6 Decontamination Activities

AMCCOM is responsible for management of the government owned APE and IPE used by private industrial firms in the manufacture of DU munitions.

DESCOM has the responsibility for cleanup of DU contaminated material. Facilities for such cleanup appear to be inadequate as demonstrated by recent incidents in which two M60A3 tanks containing DU ammunition were burned in a fire in Germany that resulted in melting or burning of the DU components. (We are unaware of the specific cause of this fire.) The radioactivity was contained within the tanks but they could not be cleaned or repaired in Germany. AMCCOM, as NRC licensee of DU munitions, provided guidance to TECOM on decontamination, packaging, hazards and transportation of the tanks to Anniston Army Depot in Alabama. This was conducted in accordance with TB-9-1300-278, which is the Army guidance document for management of accidents involving DU materials. The shipment of the tanks was coordinated between the Army commands in Germany, TECOM HQ, MAC HQ at Scott AFB, AMCCOM HQ, DESCOM HQ and Anniston Army Depot and the air shipment of the tanks was completed about two weeks after the fire. The tanks were inspected at Anniston and it was determined that they could not be cleaned or repaired and would be disposed of as low level radioactive waste at the Chem-Nuclear facility in Barnwell, SC. DESCOM did not have a facility capable of removing DU contamination from the tanks, and therefore it was necessary to bury both tanks in the Barnwell low level radioactive waste disposal facility.

There are no major environmental or health and safety obstacles to establishment of an Army decon facility.

6.2.7 Recycle Activities

Currently there are reported to be DU warheads for tank ammunition at Milan Army Ammunition plant that have not been up-loaded and which will be scheduled for demilitarization. Additional rounds are expected to be recycled from Europe to Sierra Army Depot. These may require demilitarization. The number of DU rounds requiring demilitarization can be expected to increase as weapon systems are upgraded and as normal deterioration causes ammunition lots to be recycled from storage or from the field. If DU ammunition were withdrawn from the inventory, a much larger demilitarization requirement would result. Under the Single-Manager system for ammunition, the Army is responsible for demilitarization of Air Force and Navy ammunition. The Navy is expected to discontinue use of DU rounds in the Phalanx system, and the Air Force will have

a growing quantity of GAU-8 30 mm rounds scheduled for demilitarization. There are currently unserviceable GAU-8 rounds at Eglin AFB.

We have been told that some older depot maintenance work requirements (DEMWRs) for demilitarization cannot be performed as written or may result in contaminated material being sold as scrap. Further investigation of these issues should be performed.

When DU demilitarization capabilities are developed, they will necessarily be in plants equipped to handle DU and will be subject to the safety and environmental management controls which are applied to other DU operations.

6.2.8 Summary Assessment

Worker protection appears to be adequate at all installations. Comprehensive health and safety plans have been developed and implemented. Preemployment and refresher training programs ensure personnel are advised of the potential hazards associated with testing DU penetrators and instructed in the proper use of protective equipment.

Environmental monitoring programs have been developed and implemented at facilities. Data from these programs suggests that DU contamination is not migrating for the DU firing ranges, and is not a significant environmental threat. Additional information is needed regarding long term effects. Detailed environmental studies are currently in progress at certain sites.

TABLE 6-1

DEPLETED URANIUM EXPOSURE PATHWAYS

SOURCE	TRANSPORT MEDIUM	EXPOSURE POINT	EXPOSURE ROUTE	CONTROLS
Fire or explosion during storage, transportation, decon and recycle activities	Air/Fugitive dust	Breathing zone of firefighters or other personnel in area	Inhalation, Dermal contact	Respirators, Protective clothing Personnel decontamination, Site cleanup, Monitoring, Medical surveillance
Same as above	Surface water run-off during firefighting	Personnel in run-off pathway	Dermal contact	Restrict personnel entry to fire zone until post-fire cleanup Avoid surface water contact Decontaminate boots and protective gear of firefighters Monitor area and cleanup radioactive contamination
Target impact during test firing; aerosolization,	Air/Fugitive Dust	Breathing zone of personnel near firing range	Inhalation, Dermal contact	Respirators, Protective clothing, Personnel decontamination Site cleanup, Monitoring, Medical surveillance, Enclosure targets.
Same as above	Soil Excavation	Same as above	Same as above	Same as above

TABLE 6-1 (continued)

DEPLETED URANIUM EXPOSURE PATHWAYS

SOURCE	TRANSPORT MEDIUM	EXPOSURE POINT	EXPOSURE ROUTE	CONTROLS
Same as above	Groundwater	Drinking water supply	Ingestion	Water treatment, Water source closure, Site cleanup, Monitoring
Same as above	Surface water run-off	Personnel in run-off pathway	Dermal contact	Run-off containment structures, Restrict access to target area, Avoid surface water contact, Personnel decon-ination, Monitoring, Site cleanup
Same as above	Ecosystem uptake	Ecosystem contact	Food Web	Same as above. Restrict consumption of affected biota

NOTE: These pathways do not include manufacturing activities, and also are not a comprehensive listing of all pathways.

7.0 POTENTIAL ARMY INITIATIVES[1]

7.1 PRODUCTION

This section describes recommendations for actions the Army should consider taking as depleted uranium penetrator production and/or recycling will continue for the foreseeable future. These recommendations are preliminary and based only on limited information from the site visits and literature review.

The two major environmental issues are:

(1) airborne contamination, especially in the event of fires at the plant, and

(2) generation of radioactive and mixed waste, resulting in the need to utilize burial sites at a significant expense to the Army.

It appears that other environmental concerns are appropriately managed in the current operations.

Based on these issues we recommend the Army consider the following initiatives:

* Study possible additional safeguards to prevent airborne release in the event of fire such as:
  - methods of filter system protection
  - backup filter systems in case of fire destruction (sand filters)
  - a general review of all operations to determine if further fire prevention and protection measures are warranted and practical (including emergency response plans) and accident consequence evaluations

* Review worker safety issues related to ventilation system fires such as:
  - efficacy of providing workers with emergency respiratory protection
  - automated fire protection in ventilation systems which allows faster evacuation of personnel

* Encourage and sponsor waste reduction and recycle research such as:
  - super-compaction
  - recycle of magnesium fluoride slag as steel-making flux

---

[1]Additional recommendations are contained within other sections of this document, primarily in Chapter 2.

- phase-out of barium chloride salt baths for heating of billets
- eliminate nitric acid from the pickling process for cleaning derbies
- development of new and improved equipment decontamination methods

* Study the development of an integrated and efficient waste management system.

Should the Army decide to implement tungsten penetrator production, we recommend additional environmental assessments be conducted of tungsten penetrator production to minimize potential issues of concern to workers and the environment.

7.2 ARMY OPERATIONS

7.2.1 Test firing of DU Ammunition

Methods to increase recovery rates for DU penetrators should be investigated. Consideration should be given to test firing of DU ammunition on ranges which are dedicated, and which are not used for test firing of explosive or other types of ordnance.

7.2.2 Test Firing of Tungsten Ammunition

The health risks of tungsten in hard target test firing should be investigated. One study is nearing its conclusions on this topic. Previous studies on aerosols produced by tungsten welding rods may be useful in investigating this issue.

7.2.3 Soft Target Testing Strategy

A detailed analysis to optimize design of soft target ranges for DU and tungsten firing should be conducted. Allowing the penetrators to travel unimpeded until they come to rest down range from the soft target minimizes the production of fragments and particulates, but distributes the penetrators over a wide area which complicates recovery. The use of bullet catchers of current design causes fragmentation and aerosolization, and creates a maintenance and radioactive waste management problem. The possible use of soft media bullet catchers should be included in this investigation.

7.2.4 Research

A number of research areas are potentially applicable to penetrator operations. These areas include:

* Penetrator material choice, production method, coatings, etc. to possibly decrease environmental impacts.

* Waste reduction methods and technologies at ranges and other sites. Range penetrators and fragments may be recyclable into new penetrators.

* DU contaminated soil cleanup technologies.

7.2.5 Tungsten Recovery from Ranges

Studies should be conducted regarding the feasibility of tungsten penetrator recovery on ranges for economic purposes (salvage). The environmental impacts and need for tungsten recovery from range sites for environmental reasons should also be investigated.

7.2.6 Sampling Plans

Consideration should be given to environmental sampling of all potential contaminants on ranges in both monitoring programs and RI/FS work. This would include any heavy metals utilized as well as potential contaminants from explosives in UXO.

7.2.7 Low Level Waste Disposal

Ensure that current management methods will position the Army appropriately when compact arrangements are set to begin in 1993.

7.2.8 Environmental and Health Investigations

Ensure that detailed RI/FS studies are appropriately managed and funded at all applicable penetrator testing sites. Also, assess combat impacts of (DU) kinetic energy penetrators with regard to military and civilian exposures as well as potential battlefield cleanup requirements.

7.2.9 Decontamination and Recycle

Ensure that current management methods are appropriate to identify and implement appropriate decontamination and recycle activities.

7.2.10 Tungsten Life Cycle Controls

Ensure that appropriate life cycle controls are implemented when and if tungsten penetrator production commences.

7.2.11 Future DU Enrichment Processes

As proposed uranium enrichment processes will lead to DU with a higher specific activity, the amount of DU currently stockpiled should be assessed to ensure that supplies are adequate for long-term Army requirements.

7.2.12 Centralized Penetrator Management Office

It has become clear throughout our study that the size and complexity of penetrator issues have resulted in less than optimal management of the munitions life cycle. We suspect that a myriad of reasons are responsible for this situation. It is conceivable that the existing management structure can be improved to result in improved life cycle management. However, we recommend consideration be given to establishment of a centralized penetrator management office. This would allow for issues to be reviewed and acted upon in a comprehensive manner, and by its very existence would give added emphasis to the importance of penetrator management. While not our primary concern, the public relations impacts of this action may further justify its implementation. Different commands involved in penetrator management implement different procedures for these munitions, and standardization of procedures could be fostered by a penetrator program office.

This recommendation has not been studied beyond the conceptual stage, and further investigation is warranted.

8.0 DECONTAMINATION AND DECOMMISSIONING IMPACTS OF PENETRATOR MATERIAL CHOICES

A decision by the Army to switch from DU to tungsten penetrator production will have a number of impacts. This section solely covers the D & D impacts of partial or total transition to tungsten penetrators.

8.1 PRODUCTION SITES

There are four alternatives for production sites if DU penetrator production is ended. These alternatives are: (1) continued DU operations other than penetrator manufacture; (2) DU manufacturing termination and plant conversion to other manufacturing of similar type (i.e., foundry and machining); (3) plant decommissioning, dismantling, and restricted land use; (4) plant decommissioning and land release for general use.

8.1.1 Continued DU Operations Other Than Penetrator Manufacture

In this case, it is found that there is sufficient other demand for DU components (e.g. boat keels, aircraft counter-weights, etc.) to allow continued manufacturing of billets and fabrication of products or that alternative DU activities are undertaken, such as recycling of penetrator inventories. It is assumed that some percentage of the machinery would be decommissioned. In the case of a change to recycling, this would likely be a large percentage of the equipment (perhaps all of the foundry equipment, for example).

8.1.2 Decommission and Use Site for Restricted Purposes

In this case, the plant would be totally dismantled and the site remediated. However, the standards for cleanup would be tempered with the consideration that use of the land would be administered under certain restrictions. Certain industrial applications or simply reserve of the land could be possibilities. Probable restrictions include forbidding use by the general public for residences, farming, parks, schools, or similar uses. Such restrictions would have to be maintained indefinitely and probably would incur some costs of administration.

8.1.3 Decommission and Use Site for General Purposes

This would necessitate dismantling the plant and site cleanup to very stringent standards so that the land could be released for any purpose. The standards for such cleanup would be many times more stringent than for a restricted use status. The cleanup would be much more costly but would not entail any continued cost, except possibly for monitoring, once completed.

8.2 ARMY FACILITIES

Similar scenarios exist for Army facilities including testing and storage sites. Once DU production and fielding cease, there will likely be regulatory requirements to decommission and decontaminate facilities. D & D work will probably be a phased requirement as DU penetrator operations cannot be eliminated overnight and recycling actions would probably be implemented.

8.3 COMBINED PRODUCTION OF DU AND TUNGSTEN PENETRATORS

In this scenario, both DU and tungsten penetrators would be produced and fielded. NRC D & D requirements would not take effect because facilities would not have reached the end of their useful life. It is likely, however, that NRC and other political pressures would require interim actions regarding retrieval of DU penetrators on ranges.

9.0 COSTS

9.1 DECONTAMINATION AND DECOMMISSIONING OF PRODUCTION FACILITIES

It is assumed that the facilities would be decommissioned in a similar manner to the DU penetrator production site previously decommissioned, and that all process equipment would be disposed of either as waste or decontaminated and recycled. Note that past estimates have indicated that equipment decontamination and recycle costs are nearly the same as those for burial with decontamination. This will change as burial charges increase (probably double in the mid-1990's), waste packaging improves (supercompaction), and more efficient and economic decontamination techniques are developed.

Government closure estimates are available for decontamination and decommissioning costs for DU penetrator production sites.

9.2 RANGE CLEANUP COSTS

Costs for range cleanups cannot be accurately estimated at this time. Beyond the presumed need for DU penetrator recovery, there is no clear consensus on what cleanup measures, if any, will be required. Cleanup costs for sites intended for uncontrolled use (base closure) will have to meet strict requirements, and therefore will have significantly higher cleanup costs than sites which will remain controlled by the Army.

JPG officials have estimated the cost of cleaning up the 500 acre DU contaminated area using the cleanup costs at Eglin AFB, FL as a model. These costs are outlined below.

Site survey and location of penetrators	$ 2.6 million
Collection of surface penetrators	0.34
Collection of subsurface penetrators	11.
Collection of and transportation of contaminated soil	223.
Transportation of penetrators	0.00 (included above)
Revegetation of area	0.8
Cementing and burial of contaminated material	470.
TOTAL	707.74 million

JPG officials stressed that this cost data is very preliminary. There is significant doubt as to whether this estimate bears any meaningful relationship to future cleanup expenditures. More realistic costs may become available upon completion of the RI/FS by USATHAMA. The above estimate assumes that there will be collection and transportation of contaminated soil along with burial at LLW sites. Apart from concerns regarding burial capacity and lack of a consensus on what will constitute a remediated site, soil remediation or waste reduction technologies could possibly be implemented to significantly reduce costs from those estimated above.

Minimum costs for DU range remediation can probably be assumed. It appears that DU penetrator recovery efforts will probably be required on the 9,450 acres at Aberdeen, Jefferson and Yuma Proving Grounds. Remedial action on ranges will be severely complicated by unexploded ordnance issues.

9.3 EQUIPMENT DECONTAMINATION

The capability of Seneca Army Depot (SEAD) to clean and recycle DU contaminated IPE was assessed by an AMCCOM report. SEAD has an NRC license for DU operations, a trained work force, ventilation, filters, and a worker protection safety program. They successfully cleaned 11 igloos containing radioactive contamination. The cost was $98,000 and involved 98 tons of waste material. The Army estimates that facility modifications costing an estimated $50,000 would be required for an IPE cleansing site at SEAD and possibly an additional $50,000 for equipment. Steam cleansing, grit blasting and possibly

other procedures for IPE cleaning and renovation would be used. Real time air-monitors and Radiac instrument calibration equipment would be required.

APPENDIX A

BIBLIOGRAPHY

1. Assessments

1a. U.S. Army Toxic and Hazardous Materials Agency. 1977. Installation Assessment of Frankford Arsenal. Records Evaluation Report No. 115.

1b. Battelle Columbus Laboratories. 1978. Final Report on Detailed Survey and Alternative Assessment of Frankford Arsenal. Chemical Demilitarization and Installation Restoration, Contract No. DAAK11-78-C-0047.

1c. Oak Ridge National Laboratory. 1986. Environmental Assessment for Depleted Uranium Waste Disposal at Eglin Air Force Base, Florida. U.S. Air Force Engineering and Services Center, Contract No. DE-AC05-840R21400.

1d. Environmental Science and Engineering, Inc. 1981. Installation and Assessment of Aberdeen Proving Ground-Aberdeen Area. U.S. Army Toxic and Hazardous Materials Agency, Report No. 301. [DRXTH-ES-1A-81301].

1e. JTCG/ME. 1974. Medical and Environmental Evaluation of Depleted Uranium, Volume I. Special Report.

1f. Department of the Army. 1980. Testing of Depleted Uranium Penetrator Munitions. Headquarters, USA Aberdeen Proving Ground.

1g. Ebinger, M. H., et. al. 1989. Preliminary Report on the Long-Term Fate of DU at Aberdeen and Yuma Proving Grounds, Phase I: Geochemical Transport and Modeling. Los Alamos National Laboratory.

1h. USCSTA. ND. Environmental Assessment for Construction and Operation of DU Containment Fixture at Ford's Farm, Aberdeen Proving Ground, MD. Report.

1i. Erikson, R. L. et. al. 1989. Environmental Behavior of Uranium Derived from Depleted Uranium Alloy Penetrators. U.S. Army Combat Systems Test Activity, Contract No. DE-AC06-76RLO-1830.

1j. ARDEC Public Affairs. 1987. Executive Summary - Depleted Uranium and Tungsten Alloy Cost & Performance Study. Manuscript No. 12-87.

1k. AMSMI-SF. 1988. Use of Depleted Uranium (DU) in MICOM Weapon Systems. Memorandum.

1l. Department of the Army. 1989. Depleted Uranium (DU). Memorandum for Commander, U.S. Army Materiel Command.

1m. U.S. Army Armament Research and Development Command. 1978. Use of Depleted Uranium Munitions Hazard Evaluation. Draft Report.

1n. U.S. Army Corps of Engineers and Michael Brandmen Associates, Inc. 1987. Final Environmental Assessment United States Army, Yuma Proving Ground. U.S. Army Yuma Proving Ground, Contract No. DACA 09-86-0-0011.

1o. Department of the Army. 1987. Direct Fire Weapons Range Environmental Assessment, U.S. Army Yuma Proving Ground, Yuma, Arizona.

2. Cleanup

2a. Lillie, A. F. 1981. Final Report for the Frankford Arsenal Decontamination/Cleanup Program. U.S. Army Toxic and Hazardous Materials Agency, Report No. DRXTH-FS-CR-80085.

2b. United States General Accounting Office. 1989. Modernization and Cleanup Problems are Enormous in the Nuclear Weapons Complex. Keith O. Fultz Testimony for the Committee on the Budget, United States Senate.

2c. CDR, USAMC, AMCSF-P, To CDR, AMCCOM, AMSMC-SF, 12 Apr. 88, Subject: Nuclear Regulatory Commission (NRC) License SUC-1380 Amendment No. 10 (LCAAP) Lake City.

3. Closure Plans

3a. Bernhardt, D. E., D. H. Owen, and V. C. Rogers. 1988. Facility Closure Report, Depleted Uranium Manufacturing Facility. Rogers and Associates Engineering Corporation, RAE-8509/5-2.

4. Decontamination

4a. U.S. Department of the Army. 1989. Nuclear Regulatory Commission (NRC) General Requirements for Decommissioning Nuclear Facilities. U.S. Army Materiel Command Memorandum for Commander Lake City Army Ammunition Plant.

4b. Manion, W. J. and T. S. LaGuardia. 1980. Decommissioning Handbook. Nuclear Energy Services, Inc. Contract No. EP-78-C-02-4775.

4c. United States Environmental Protection Agency. 1988. Technological Approaches to the Cleanup of Radiologically Contaminated Superfund Sites. Office of Research and Development, EPA/540/2-88/002.

4d. Hanson, S.W., D.B. Wilson, N.N. Gunaji, and S.W. Hathaway. Removal of Uranium from Drinking Water by Ion Exchange and Chemical Clarification. EPA 600/2-87/076, Dec. 1987.

5. Disposal

5a. Cytron, S. J. 1989. U.S. Army Radioactive Waste Disposal Support Plan (Draft). U.S. Army Armament Research, Development and Engineering Center, Technical Report ARAED-TR-89001.

5b. Chem-Nuclear Systems, Inc. 1986. United States Air Force Depleted Uranium Waste Eglin Air Force Base, Florida. HAZWRAP (Hazardous Waste Remedial Action Program) Report No. 1, Detailed Implementation Plan, Contract No. 22X22251V.

5c. Department of the Air Force. 1983. Expended DU Ordnance Disposal. Memorandum.

5d. Department of the Air Force. 1985. Radioactive Waste Disposal Procedures. Memorandum.

6. Disposal Alternative Studies

6a. National Systems Management Corporation. 1988. Analysis and Assessment of Sead Capability for Processing Depleted Uranium Contaminated Manufacturing Equipment. U.S. Army Industrial Engineering Activity Technical Report, Contract No. DAAA08-86-D-0205.

6b. Mallory, C. W., W. S. Sanner, Jr., and J. G. Funk. 1985. Alternatives for Disposal of Depleted Uranium Waste. Air Force Armament Laboratory Final Report for Period October 1984-August 1985. Report No. AFATL-TR-85-78.

6c. Gordon, J. 1988. Review and Analysis of Disposition Alternatives for Depleted Uranium Contaminated Manufacturing Equipment. U.S. Army Industrial Engineering Activity, Technical Report Contract No. DAAA08-86-D-0205.

6d. Department of the Air Force. 1984. Statement of Work (SOW) for Depleted Uranium Disposal Study. Memorandum.

6e. Department of the Air Force. 1986. Letter of Need. Memorandum.

7. Environmental Studies

7a. Becker, N. M., E. B. Vanta, and R. C. Crews. 1989. Environmental Monitoring for Depleted Uranium at Eglin Air Force Base Test Areas C-64, C-64C, and C-74L, 1974-1988. Draft Report.

7b. Hooker, C. D. and D. E. Hadlock. 1986. Radiological Assessment Test of the 120-MM, APFSDS-T, M829 Cartridge: Metal Shipping Container. Battelle Pacific Northwest Laboratory, Contract No. DE-AC06-76LRO 1830.

7c. Elder, J. C. and M. C. Tinkle. 1980. Oxidation of Depleted Uranium Penetrators and Aerosol Dispersal at High Temperatures. Los Alamos Scientific Laboratory, Contract No. W-7405-ENG. 36.

7d. Chambers, D. R., et. al. 1982. Aerosolization Characteristics of Hard Impact Testing of Depleted Uranium Penetrators. U.S. Army Armament Research and Development Command, Technical Report ARBRL-TR-02435.

7e. Wilsey, E. F. and E. W. Bloore. 1989. M774 Cartridges Impacting Armor-Bustle Targets; Depleted Uranium Airborne and Fallout Material. Ballistic Research Laboratory Memorandum Report BRL-MR-3760.

7f. Bartlett, W.T., et. al. 1979. Radiation Characterization, and Exposure Rate Measurements from Cartridge, 105-mm, APFSOS-T, XM774. Battelle Pacific Northwest Laboratory, Contract No. EY-76-C-06-1830.

7g. Mishima, J., et. al. 1986. Hazard Classification of the Cartridges 105-MM, APFSDS-T, M774 and M833 in Metal Shipping Containers by Analogy to Previous Test Results. Battelle Pacific Northwest Laboratory, Contract No. DE-AC06-76RLO 1830.

7h. Parkhurst, M. A. and K. L. Soldat. 1989. Radiological Assessment of the 105-MM, APFSOS-T, XM900E1 Cartridge. Battelle Pacific Northwest Laboratory, Contract No. DE-AC06-76RLO 1830.

7i. Foley, R. D. and L. M. Floyd. 1989. Results of the Followup Site Verification Survey at Eglin Air Force Base, Fort Walton Beach, Florida. Oak Ridge National Laboratory, Contract No. DE-AC05-840R21400.

7j. Foley, R. D. and R. F. Carrier. 1989. Results of the Baseline Radiological Survey at Eglin Air Force Base, Fort Walton Beach, Florida. Oak Ridge National Laboratory, Contract No. DE-AC05-840R21400.

7k. Esposito, M. P., et. al. 1987. Decontamination Techniques for Buildings, Structures, and Equipment. Noyes Data Corporation.

7l. Comer, R. H. 1980. Radiological Aspects of Open-Site Testing of DU Penetrators at the BRL Transonic Range, APG, MD. U.S. Army Armament Research and Development Command Special Publications ARBRL-SP-00015.

7m. Patrick, M. A. and J. C. Cornette. 1978. Morphological Characteristics of Particulate Material Formed from High Velocity Impact of Depleted Uranium Projectiles with Armor Targets. Air Force Armament Laboratory, Final Report for Period October 1977-October 1978. Report No. AFATL-TR-78-117.

7n. Kesselman, R. 1989. Untitled Report.

7o. Magness, C. R. 1985. Environmental Overview for Depleted Uranium. U.S. Army Armament, Munitions & Chemical Command, Report No. CRDC-TR-85030.

7p. Department of the Air Force. 1986. Demonstrations of Depleted Uranium Waste Processing Technologies. Memorandum.

7q. Hoegler, J. M. 1985. Data Analysis and Report on Magnetic Separability of Uranium from Sand. Oak Ridge National Laboratory.

7r. Crews, R. C. and D. D. Harrison. ND. Environmental Implications of Testing Depleted Uranium Munitions Underwater.

7s. U.S. Air Force. ND. DU Sampling Grid Map.

7t. U.S. Air Force. ND. Test Area C-64 Pilot Plan Map.

7u. AFATL. 1988. Laboratory Work Request and Report No. 8328. Project No. 9993G920.

7v. TESTW/TFRL. 1986. Laboratory Work Request and Report No. 6099. Project No. ARMDGB05.

7w. SGPE. 1983. Laboratory Work Request and Report No. 3235. Project No. 06AL0110.

7x. Armament Development and Test Center. 1976. Environmental Impact Assessment Data Base for Eglin AFB, FL, Volumes I and II.

7y. No Author. ND. Review of the Environmental Quality Aspects of the TECOM DU Program at Jefferson Proving Ground, Indiana.

7z. Department of the Army. ND. Environmental Radiological Monitoring Plan - DU Munitions. U.S. Army, Yuma Proving Ground, Yuma, Arizona.

8. Facility Descriptions

8a. Harford County Chamber of Commerce. 1989. Harford Chamber of Commerce Salutes Aberdeen Proving Ground and the Maryland National Guard. Military Appreciation Week, May 13-20, 1989. Newspaper supplement May 17, 1989.

8b. U.S. Army Combat Systems Test Activity. ND. DU Containment Fixture Superbox. Informational Pamphlet.

8c. U.S. Department of the Army. 1987. Mission, Organization and Functions Regulation. U.S. Army Combat Systems Test Activity, USACSTA Regulation No. 10-1.

9. Health Studies

9a. Wright, E. G. and R. A. Markland. 1977. Radiological Survey and Assessment of Potential Radiation and Chemical Effects of Depleted Uranium (DU) Alloy Penetrators on Research Personnel Using an M-48 Tank as Test Vehicle. USA Ballistic Research Laboratory, Report No. 1969.

9b. Scherpelz, R. I., et. al. 1986. DUDOSE - Computer Codes for Calculating Doses Resulting from Accidents Involving Munitions Containing Depleted Uranium. Battelle Pacific Northwest Laboratory, Contract No. DE-AC06-76RLO 1830.

9c. Prado, K. L. ND. External Radiation Hazard Evaluation of GAU-8 Apit Munitions. USAF Occupational and Environmental Health Laboratory, Technical Report No. TR 78-106.

9d. Department of the Air Force. 1979. Radiation Survey of GAU-8A ALS Container and Loaded Vehicle at Chino Hills, CA. Memorandum

9e. Cole, L. W. 1989. Health Assessment of Field Use of DU in Chemical Energy Warheads.

10. Licenses and Permits

10a. Department of the Army. 1989. Application for Renewal of NRC License SMB-141. U.S. Army Ballistic Research Laboratory.

10b. Harris, H. G. 1988. Application for Material License, Test Areas (TA)C-64 and (TA)C-80, Eglin AFB, FL. NRC license application.

10c. Department of the Army. 1989. Application of Renewal for Source Material License SUB 1435, Soft Impact of DU Munitions. U.S. Army, Jefferson Proving Ground.

10d. Department of the Army. 1989. U.S. Nuclear Regulatory Commission Materials License, SMB-1411, Amendment No. 3. Docket No. 040-08814.

11. Operational Data

11a. Airtherm Manufacturing Company. 1977. DU Gun Ammunition Test Facility Eglin Air Force Base, Florida. Letter on Air Handling Units. C-64.

12. Organizational Charts and Information

12a. U.S. Department of the Army. 1987. This is TECOM. U.S. Department of the Army, TECOM Pamphlet No. 360-1.

12b. U.S. Army Aberdeen Proving Ground Support Activity. 1988. Organizational Directory.

12c. U.S. Army Test and Evaluation Command. 1989. Staff Directory.

12d. Aberdeen Proving Ground. 1962. Range Control Map. Facilities Engineering Branch, Drawing No. A.P.G. 13481-1.

12e. U.S. Army Armament, Munitions and Chemical Command. 1989. USADACS Staff Directory Chart. U.S. Army Defense Ammunition Center and School.

12f. U.S. Department of the Army. 1981. Possible Negative Publicity/Worker Safety. Headquarters U.S. Army Materiel Development and Readiness Command, Memorandum for Chief of Staff.

12g. U.S. Army Armament, Munitions and Chemical Command. 1989. AMCCOM Special Edition. Organizational Day Issue Newsletter.

13. Recycling/Reclamation

13a. Walz, M. J. 1982. Depleted Uranium Test Range Fragment Reclamation. Air Force Armament Laboratory Final Report for Period November 1981-June 1982. Report No. AFATL-TR-82-49.

13b. Bucci, S. A., J. Y. Nalbandian, and D. M. Kagan. 1981. Recycling/Disposal Alternatives for Depleted Uranium Wastes. Air Force Armament Laboratory Final Report for Period June 1980-September 1980. Report No. AFATL-TR-81-4.

14. Regulatory

14a. U.S. Department of the Army. 1983. Radioactive Waste Shipment Violations. Letter to South Carolina Department of Health and Environmental Control.

14b. U.S. Department of the Army. 1989. Environmental Survey Guidance for Potential Construction Sites. Memorandum from Army Safety Center.

14c. Health Physics Society Standards Committee. 1986. Surface Radioactivity Guides for Materials, Equipment, and Facilities to be Released for Uncontrolled Use. Draft Report.

14d. U.S. Atomic Energy Commission. 1974. Termination of Operating Licenses for Nuclear Reactors. Regulatory Guide 1.86.

14e. U.S. Department of the Air Force. 1982. Applicability of Florida Law Regulating Disposal of Radioactive Waste. Memorandum to USAF HOSP/SGP.

14f. Environmental Reporter. 1985. Maryland Hazardous Waste Regulations. The Bureau of Public Affairs, Inc.

14g. U.S. Army/U.S. Air Force. 1988. Radioactive Waste Guidance Course. Chem-Nuclear Systems, Inc.

14h. 29 CFR Part 1910. Occupational Safety and Health Standards.

14i. 54 FR 9294. Hazardous Waste Operations and Emergency Response; Final Rule.

14j. 54 FR 26654. Worker Protection Standards for Hazardous Waste Operations and Emergency Response.

14k. 46 FR 52061. Disposal of Onsite Storage of Thorium or Uranium Wastes from Past Operations.

14l. Department of Transportation. 1986. DOT-E-9849. Letter of Exemption.

15. Safety

15a. Hazardous Component Safety Data Sheet. 1980. Depleted Uranium.

15b. U.S. Department of the Army. 1989. Investigation of Ways to Locate and Recover DU Penetrators in Hazardous Areas. U.S. Department of the Army Memorandum No. STECS-SO (385).

15c. U.S. Department of the Army. 1986. USACSTA Safety Program. USACSTA Memorandum No. 385-2.

15d. Elder, J. C., M. I. Tillery, and H. J. Ettinger. 1976. Hazard Classification Test of GAU-8 Ammunition by Bonfire Cookoff with Limited Air Sampling. Los Alamos Scientific Laboratory, Report No. LA-6210-MS.

15e. Haggard, D. L., et. al. 1986. Hazard Classification Test of the 120 MM, APFSDS-T, M829 Cartridge; Metal Shipping Container. Battelle Pacific Northwest Laboratory, Contract No. DE-AC06-76LRO-1830.

15f. Walters, J. O., J. E. Elliott and E. W. Bloore. 1979. Safety and Health Considerations for Handling Staballoy Munitions. ARRADCOM DU Task Force, U.S. Army Armament Research and Development Command.

15g. Battelle Pacific Northwest Laboratory. 1987. Radiological Hazards Associated with Depleted Uranium Munitions. U.S. Army Belvoir RD&E Center. Student Manual.

15h. American Nuclear Society. 1981. Radiation - A Fact of Life. International Atomic Energy Agency Pamphlet.

15i. Nelson, I. C. and K. R. Price. 1989. Review of Environmental Radiation Monitoring Documents for the Depleted Uranium Test Area. Battelle Pacific Northwest Laboratory, Contract No. DE-AC06-76RLO 1830.

15j. U.S. Department of the Army. 1966. Radiological and Disaster Recovery at Fixed Military Installations. Department of the Army Technical Manual, TM 5-225.

15k. Martin Marietta Ordnance Systems, Inc. 1987. General Safety Program for 105 MM Cartridges Containing "Staballoy" Penetrators. Technical Services Division.

151. USACSTA. 1988. Safeguards (Past and Present) in Testing Munitions and Other Items Containing Depleted Uranium. Briefing.

15m. Department of the Army. 1989. Nuclear Regulatory Commission (NRC) Form 3, Notice to Employees. Memorandum.

15n. Doull, J., C. D. Klaassen, and M. O. Amdur. ND. Toxicology, The Basic Science of Poisons.

15o. Headquarters, U.S. Army Material Development and Readiness Command. 1978. Handbook - Safety Procedures for Processing Depleted Uranium. DARCOM HDBK 385-1.1-78.

15p. Department of the Army. 1987. Occupational Safety and Health Program. U.S. Army Yuma Proving Ground, USAYPG Regulation No. 385-1.

16. Standard Operating Procedures (SOP's)

16a. Headquarters, Department of the Army. 1987. Guidelines for Safe Response to Handling, Storage, and Transportation Accidents Involving Army Tank Munitions Which Contain Depleted Uranium. Department of the Army Technical Bulletin, No. TB9-1300-278.

16b. Headquarters, U.S. Army Armament, Munitions and Chemical Command. 1985. Depot Maintenance Work Requirements for Demilitarization of Cartridge, 105 MM; APFSDS-T, M774 [NSN 1315-01-082-9856]. AMCCOM DMWR 9-1315-C523-X1.

16c. Headquarters, U.S. Army Armament, Munitions and Chemical Command. 1989. Depot Maintenance Work Requirements for Demilitarization of Cartridge, 120 MM; APFSDS-T, M829-(NSN 1315-01-168-6108), M829A1-(NSN 1315-01-269-2256). AMCCOM DMWR 9-1315-0000-X21.

16d. Headquarters, U.S. Army Armament, Munitions and Chemical Command. 1984. Depot Maintenance Work Requirements for Demilitarization of Cartridge, 105MM; APFSDS-T, M833 (NSN 1315-01-136-9631). AMCCOM DMWR 9-1315-C524-X20.

16e. Headquarters, U.S. Army Armament, Munitions and Chemical Command. 1984. Depot Maintenance Work Requirements for Demilitarization of Cartridge, 105MM; APDS-T, M392 (L36A1 UK), M392A1, M392A2, and M728, All NSN's. AMCCOM DMWR 9-1315-0000-X4.

16f. Department of the Army. 1982. Safety Range Control Regulations. APG Regulation No. 385-1.

16g. Department of the Army. ND. Safety (Depleted Uranium Testing) Small Caliber Indoor Range. BRL SOP 385-34-1.

16h. Department of the Army. 1987. Depleted Uranium Testing at R-9, Spesutie Island. BRL SOP 385-20-1.

16i. U.S. Army Combat Systems Test Activity. 1989. Operation: Firing of Weapons Ground-to-Ground and Ground-to-Air. SOP 385-67.

16j. U.S. Army Combat Systems Test Activity. 1989. Operation: Decontamination Procedures for Depleted Uranium (DU). SOP 385-311.

16k. U.S. Army Combat Systems Test Activity. 1985. Safety-Handling, Packaging, and Shipping Depleted Uranium (DU) Waste. SOP 385-312.

16l. U.S. Army Combat Systems Test Activity. 1987. Environmental Radiation Monitoring. SOP 385-328.

16m. U.S. Army Combat Systems Test Activity. 1988. Operation: Machining of DU Materials. SOP 385-332.

16n. No Author. 1980. Gunnery Ballistic Facility, Test Area C-74L. VPO-7915-6.

16o. No Author. 1984. Depleted Uranium (DU) Test Facility, C-64. EOP - 7603-01.

16p. Department of the Army. 1985. Handling, Use and Storage of Natural and Depleted Uranium and Thorium. BRL SOP 385-32.

16q. Department of the Army. 1987. Depleted Uranium Testing at R-14, Spesutie Island. BRL SOP 385-20.

16r. Department of the Army. 1984. Preparation and Analysis Procedures for Environmental Radiological Monitoring Plan Samples. Material Test Directorate, U.S. Army Yuma Proving Ground, Yuma, Arizona.

16s. Department of the Army. 1989. Standard Operating Procedures for DU Penetrators. U.S. Army Yuma Proving Ground, Yuma, Arizona.

17. Miscellaneous Bibliography

17a. American Conference of Governmental Industrial Hygienists, 1986, Documentation of the Threshold Limit Values and Biological Exposure Indices, Fifth Edition.

17b. American Conference of Governmental Industrial Hygienists, 1989, Threshold Limit Values and Biological Exposure Indices for 1990-1990.

17c. Army Regulations 700-64, 200-1, 200-2.

17d. Bartlett, W.T., et. al. 1979. Radiation Characterization and Exposure Rate Measurements from Cartridge 105mm, APFSDS-T, XM 774; prepared for U.S. Army under DOE Contract No. EY-76-C-06-1830.

17e. Bishop, Dr. Jay L., 1989; Demilitarization of Depleted Uranium Devices; Ammunition Equipment Directorate, Tooele Army Depot, AED Report 07-89.

17f. Bureau of Mines, U.S. Department of the Interior, Mineral Facts and Problems, (1985 Edition - Tungsten, 1980 Edition - DU).

17g. Caldwell, Dr. Stephen; Teledyne Firth Stirling, TN; personal communication.

17h. Clark, C. Canfield, Limitations in the Use of Penetrator Materials, for Tungsten Ordnance Seminars, 1984 and 1986.

17i. Glissmeyer, J.A. and J. Mishima, 1979, Battelle Pacific Northwest Laboratories, Characterization of Airborne Uranium from Test Firings of XM774 Ammunition; prepared for U.S. Army under DOE Contract No. EY-76-C-06-1830.

17j. Hadlock, Dennis and Parkhurst, Mary Ann; Battelle Pacific Northwest Laboratories; Personal Interview, November 1989.

17k. National Institute for Occupational Safety and Health, Cincinnati, Ohio; response to request for information through 1990 from the Tungsten Database.

17l. National Materials Advisory Board, National Research Council, Publication NMAB-350, Comparison of DU and Tungsten for Use as Kinetic Energy Penetrators (declassified portions), 1979.

17m. National Research Council, 1990, Committee on the Biological Effects of Ionizing Radiations, Health Effects of Exposure to Low Levels of Ionizing Radiation - BEIR V.

17n. Sheinberg, Haskell; Los Alamos National Laboratory; personal communication.

17o. Till, John E. and Schmidt, Duane W., 1990, Comparing the Environmental Health Risks of DU and W Contamination from Kinetic Energy Penetrators, Radiological Assessments Corporation, Neeses, South Carolina.

17p. Wilsey, Edward F., Radiation Measurements of an M1A1 Tank Loaded with 120mm M829 Ammunition; ARDEC; undated.

APPENDIX D

KINETIC ENERGY PENETRATORS
ENVIRONMENTAL AND HEALTH CONSIDERATIONS

Prepared for the
Kinetic Energy Penetrator Long Term Strategy Study

Volume 2
Generic Risk Assessment Report

U.S. Army Production Base Modernization Activity
Picatinny Arsenal, New Jersey 07806-5000

July, 1990

VOLUME 2
TABLE OF CONTENTS

VOLUME 2
TABLE OF CONTENTS (Continued)

VOLUME 2
TABLE OF CONTENTS (Continued)

LIST OF TABLES

ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AED	Aerodynamic Equivalent Diameter
ALARA	As Low As Reasonably Achievable
AMAD	Activity Median Aerodynamic Diameter
BEIR	Biological Effects of Ionizing Radiation
Co	Cobalt
DOD	Department of Defense
DOT	Department of Transportation
DREF	Dose Rate Effectiveness Factor
DU	Depleted Uranium
EDE	Effective Dose Equivalent
EPA	U.S. Environmental Protection Agency
Fe	Iron
HEPA	High Efficiency Particulate Air
ICRP	International Commission on Radiological Protection
IRP	Installation Restoration Program
MEI	Most Exposed Individual
Mo	Molybdenum
NCRP	National Council on Radiation Protection and Measurements
Ni	Nickel
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
PDF	Probability Distribution Function
RERF	Radiation Effects Research Foundation
Ti	Titanium
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
W	Tungsten

PREFACE

This assessment attempts, to the degree that the current state of knowledge permits, to characterize the occupational and environmental risks associated with the manufacture and use of depleted uranium (DU) and tungsten (W) munitions. Such an assessment must consider many factors, including the chemical and physical properties of these materials, their toxicity, specific conditions surrounding their manufacture and use, and their behavior in the environment. The volume of information required to accurately and thoroughly assess these risks is substantial, and such a definitive assessment is beyond the scope of this effort. Rather, a comparative and conservative approach has been taken whereby (1) the technical data needed for risk analysis is described and discussed; (2) the relative risk of DU versus W is assessed; and (3) a reasonable upper limit to the risk posed by these materials is determined. In this way, the fact that certain data were not available, or certain methodologies could not be applied should not compromise the general conclusions.

This assessment is unique in that the comparative evaluation focuses on two materials with distinctly different properties: DU, a chemical or radioactive toxin (depending on its chemical species) which has been widely studied as an occupational hazard; and W, a non-radioactive metal which has not been thoroughly characterized as an occupational hazard. Historically, different methodologies have been applied to radiological versus chemical risk assessments. This effort involves both. A further complexity is introduced by the fact that occupational safety standards which apply to DU are currently in a state of transition: new radiation protection standards, based on revised dosimetry methods, are currently being introduced (but are not as of this date in effect) and will impact DU operations. These factors, when considered with the lack of a complete database on occupational and environmental conditions at the affected locations, make this assessment a difficult task. Although the conclusions of this assessment are sound and should not be significantly affected by further review, a thorough critique of this work should be performed by experts from both the radiation and chemical risk communities to substantiate the methods and results to the point where they can be considered definitive.

The bulk of this report was prepared for submission in November, 1989. Changes to the draft document have been made based on peer review comments received from the U.S. Army as well as DU and tungsten manufacturers. The BEIR V report was released after submission of our draft document and Appendix E has been added to address findings of the BEIR V committee and impacts on our report.

1. OVERVIEW

A large number of studies have been conducted on the health effects, exposures and health risks associated with the manufacture, storage, transport, use and disposal of depleted uranium throughout its military life cycle as a kinetic energy penetrator. Far fewer studies are available for tungsten. This report summarizes data contained in the documents listed in the bibliography in a way that allows a contrasting of the differences in health risk between depleted uranium (DU) and tungsten (W) as kinetic energy penetrators. Where possible, a comparison is also made between DU-related risks in the kinetic penetrator military life cycle and those arising from background uranium concentration and radiation exposures to place the qualitative differences into quantitative perspective.

As a result of evaluating environmental and health effects of DU and tungsten, we conclude that the risk to occupational workers, military personnel, and the public is acceptable as defined by current governmental and professional standards. While much more is known about the health effects of uranium than of tungsten alloys, the comparable information on chemical toxicity indicates that insoluble DU is approximately 25 times more toxic than insoluble tungsten and soluble DU is 20 times more toxic than soluble tungsten when exposure is at the limits allowed by the regulations. When the "ALARA" concept is applied to the DU industry, it is estimated that the exposure averages between 5 and 10 percent of the limits, thereby reducing the differences in actual risk. Radiation effects are unique to DU. Therefore, this represents a risk which does not apply to tungsten. However, the radiation exposure received by workers and the public were found to result in a small risk compared to that resulting to non-workers from background radiation.

In summary, we must conclude the risk from each is acceptable when compared with natural benchmarks (i.e. background radiation risks) and administrative benchmarks (e.g., ambient or occupational standards originating with EPA, NRC, or OSHA). Both have the potential for elevated health risk due to inhalation of particulates.

A comparison of depleted uranium kinetic penetrators with tungsten kinetic penetrators must consider a wide range of factors including the cost, the availability of materials, the military effectiveness of the penetrators and the relative health risks of each material. This report addresses only the relative environmental and health risks.

1.1 PHYSICAL AND CHEMICAL PROPERTIES OF DEPLETED URANIUM AND TUNGSTEN AFFECTING THEIR USE AS KINETIC ENERGY PENETRATORS

Depleted uranium (DU) is a byproduct of the enrichment of U-235 in natural uranium by the gaseous diffusion process for the production of a fissionable fuel. DU contains less than 0.3% U-235. It has a density of 18.9 gm/cm^3 and a melting point of 1,132° C. DU is radioactive, emitting 4.18 MeV alpha particles and 0.045 MeV gamma radiation. It has a physical half-life of 4.5 billion years. Its short-lived radioactive daughters are Th-234 and Pa-234. The specific activity of DU is near 4.3×10^{-7} Ci/g, as compared to 6.77×10^{-7} Ci/g for the natural uranium isotope mixture. Therefore, DU has less risk from radiation than natural uranium.

Uranium reacts with most elements in the periodic table (Weigel 1980) and will ignite and burn in air at 700 - 1000 °C. If temperatures greater than 1000 °C are encountered, the oxide formed on the metal's surface will be primarily U_3O_8. Below 100 °C UO_2 will predominate in the surface coat. The degree of pyrophoricity of the metal is determined by a number of factors, including the surface area-to-mass ratio, impurities, alloying metals, porosity of the material, temperature and atmospheric pressure and humidity, with the most important factors being the temperature and surface area-to-mass ratio (Magness 1985).

Tungsten has a density slightly greater than the DU at 19.3 gm/cm^3. It has low reactivity and a high melting point (3,410 °C). When heavily cold worked, as in wire drawing, tungsten is the strongest metal but tungsten penetrator alloys only achieve about half the maximum strength. However, liquid phase sintering of high density tungsten alloys with Ni, Fe and Co is a low cost method for achieving good toughness, ductility and strength in high density penetrators, counterweights, etc.

The high density and high tensile strength of the two metals make them ideal as kinetic energy penetrators. The alloying metals used in the manufacture of kinetic penetrator quality DU are titanium or molybdenum at 0.75% and 2% respectively. For W kinetic penetrators the alloying metals are cobalt, iron or nickel in the approximate range of 1% to 5%.

Due to the differences in brittleness and tensile strength, a DU kinetic energy penetrator fragments into smaller pieces than a W kinetic energy penetrator under the same conditions of impact. Due to its pyrophoric nature, many of the DU fragments will spontaneously ignite following impact, resulting in a shift of the particle size probability distribution function (PDF) to a lower mean diameter. As a result of physical differences between DU and its oxides, the oxide particles tend to crumble under relatively weak mechanical forces, further shifting the particle size to even lower mean diameter.

The pyrophoric nature of DU can also be a military advantage as a penetrator, although it contributes to low level contamination of testing and combat areas with DU, which has intrinsic chemical toxicity properties (as a heavy metal) as well as intrinsic alpha and gamma radioactivity.

For W, the presence of nickel in spent penetrator fragments may lead to occupational, military and environmental exposures to elemental nickel or its oxides, which are carcinogenic when inhaled.

1.2 MANUFACTURING, TESTING, AND RECYCLING ACTIVITIES OF THE ARMY COVERED BY THE ASSESSMENT

The manufacture of depleted uranium (DU) or tungsten (W) in the form of kinetic penetrator projectiles for armor-piercing ammunition, and the subsequent testing and recycling, defines the military life cycle for each metal. If production or testing ceases, decommissioning and remediation are required to restore the occupational and ambient environments affected by the use of each metal. Each stage of the life cycle involves a set of activities.

The generic stages and activities that define the military life cycle and post-military recovery cycle of kinetic penetrators are listed below:

Manufacture

- Production of metal alloy
- Manufacture of kinetic penetrator projectiles
- Manufacture of armor-piercing rounds
- Test firing of armor-piercing rounds
- Recycling of waste metal alloy
- Waste management

Recycle

- Withdrawal of ordnance
- Destructive firing or disassembly of armor-piercing rounds
- Recycling of scrap to non-kinetic penetrator applications
- Waste management

Decommissioning

- Shut-down of kinetic penetrator-related operations
- Sampling and analysis of shut-down occupational and ambient environments
- Cleaning
- Mothballing or dismantling
- Recycling of edifices, equipment and sites for non-kinetic penetrator uses
- Waste management

Remediation

- Sampling and analysis to define nature, size, and magnitude of contamination
- Cleanup
- Waste management

The generic processes and unit operations that define each activity of the military life cycle and the post-military recovery cycle are listed in Table 1-1 through 1-4.

Table 1-1 KINETIC PENETRATOR PRODUCTION ACTIVITIES

ACTIVITY: Manufacture of Kinetic Penetrator Projectiles

PROCESSES:
- Transport of Raw materials to Manufacturing Facility
- Transport of Rejected Penetrators to Manufacturing Facility
- Storage of Raw and Recycled Materials
- Manufacture of Metal Alloy
- Rolling or Extrusion of Milling Blanks
- Milling
- Milling-Related Fires
- Polishing of Milled Projectiles
- QC Inspection of Projectiles
- Storage of Projectiles
- Waste Collection
- Waste Collection-Related Fires
- Waste Storage
- Waste Treatment
- Waste Disposal

ACTIVITY: Assembly of Armor-Piercing Munitions

PROCESSES:
- Transport of Flawed Rounds To Assembly Plant
- Transport of Projectiles To Assembly Facility
- Storage of Flawed Rounds
- Storage of Penetrators
- QC Inspection
- Storage of Rejected Penetrators
- Cleaning of Penetrators
- Joining of Projectile to Cartridge
- QC Inspection
- Storage of Rejected Rounds
- Disassembly of Rejected Rounds and Flawed Rounds
- Storage of Finished Rounds
- Storage of Disassembled Aluminum Windscreens
- Waste Collection
- Waste Collection-Related Fires
- Waste Storage
- Waste Treatment
- Waste Disposal

Table 1-2 SHELL TESTING ACTIVITIES

ACTIVITY: Testing

PROCESSES:
- Transport of Armor-Piercing Rounds To Test Facility
- Storage
- Transport to Test Range
- Loading of Weapon
- Test Firing
- Testing-Related Fires
- Post-Firing Inspection of Target
- Post-Firing Cleanup
- Storage of Penetrator Fragments
- Return of Fragments to Penetrator Manufacturing Facility
- Return of Duds to Assembly Facility
- Waste Collection
- Waste Collection-Related Fires
- Waste Storage
- Waste Treatment
- Waste Disposal

Table 1-3 DEMILITARIZATION ACTIVITIES

ACTIVITY: Collection of Armor-Piercing Shells from Military Installations

PROCESSES:
- Unloading of Weapon Magazines
- Unloading of Storage Lockers
- Centralization of Armor-Piercing Munitions Destined for Demilitarization

ACTIVITY: Disassembly of Armor-Piercing Munitions

PROCESSES:
- Transport of Demilitarized Rounds to (Dis)Assembly Facility
- Storage of Demilitarized Rounds
- Disassembly
- Storage of Disassembled Kinetic Penetrators
- Storage of Contaminated Aluminum Windscreens
- Waste Collection
- Waste Collection-Related Fires
- Waste Storage
- Waste Treatment
- Waste Disposal

ACTIVITY: Destructive Firing of Armor-Piercing Munitions

PROCESSES:
- See Testing

Table 1-4 DECONTAMINATION AND REMEDIATION ACTIVITIES

ACTIVITY: Dismantling of Armor-Piercing Munitions Military Testing Facilities

PROCESSES:
- Decontamination of Contaminated Surfaces
- Disassembly of Heavy Equipment
- Removal of Light Equipment
- Disassembly of Facility Structures
- On-Site Storage of Equipment and Parts
- Transport of Equipment and Parts Off-Site
- Waste Collection
- Waste Collection-Related Fires
- Waste Storage
- Waste Treatment
- Waste Disposal

ACTIVITY: Sampling of Contaminated Soil, Ground Water, and Sediment at Armor-Piercing Munitions Military Testing Facilities

PROCESSES:
- Site Visitation
- Site Sampling
- Sample Collection-Related Waste Storage
- Sample Collection-Related Waste Analysis
- Transport of Sample Collection-Related Wastes To On-Site or Off-Site Disposal
- Sample Collection-Related Waste Disposal
- Sample Storage
- Sample Analysis
- Transport of Sample Analysis Waste for Off-Site Disposal
- Sample Waste Disposal

ACTIVITY: Remediation of Contaminated Soil, Ground Water and Sediment at Armor-Piercing Munitions Military Testing Facilities

PROCESSES:
- Excavation
- Storage of Excavated Soil On-Site
- Ground Water Purging
- Dredging
- Treating Contaminated Ground Water or Dredged Contaminated Sediment
  Dewatering Waste-water Prior to Discharge to Surface Water or POTW
- Storage of Dewatered Dredged Material On-Site
- Waste Stabilization On-Site
- Waste Disposal On-Site
- Transport of Stabilized Wastes Off-Site for Disposal
- Waste Disposal Off-Site

From these activities, processes and unit operations must be selected for the side-by-side comparison of the occupational and environmental risks associated with the use of DU versus tungsten in the kinetic penetrator arsenal.

To make this selection, a set of objective criteria have been evolved that define the potentially significant concerns to be addressed in the comparison study. Those criteria are:

1. The activity must be unique to the use of the metal as a kinetic penetrator.
2. The number of individuals exposed; the magnitude, duration or frequency of exposure; or the intrinsic hazard per unit exposure are high, either singly or in some combinations.
3. There is sufficient information for both metals with which to make meaningful comparisons.
4. The significance of the risk associated with a given activity cannot be attributed to past practices no longer considered acceptable.
5. The significance of the risk associated with a given activity cannot be attributed to an assumption of noncompliance with any applicable Federal, State or local regulation, rule, standard, ordinance or restriction, where compliance is attainable with existing technology.

Consistent with these criteria, this generic risk assessment focuses on day-to-day operations at each stage of the military and post-military life cycles that represent potentially significant occupational, military personnel, or public health risks.

1.3 HEALTH HAZARDS AND EXPOSURES ASSOCIATED WITH THE USE OF DEPLETED URANIUM OR TUNGSTEN AS KINETIC ENERGY PENETRATORS

In this section the health hazards and occupational and environmental standards associated with depleted uranium (DU) and tungsten (W) are summarized, followed by a listing of the potentially significant exposures associated with the military life cycle of kinetic energy penetrators.

1.3.1 Health Hazards

1.3.1.1 Depleted Uranium

DU offers both chemical and radiological toxicity health hazards. Radiological health hazards include both internal and external alpha and gamma irradiation associated with DU and its short-lived daughters. The human health hazards associated with a unit exposure to alpha, beta or gamma radiation have been calculated from epidemiological data generated from historical exposure associated with the use of fission bombs. Internal irradiation hazards associated with inhalation and incidental ingestion of DU particles in both insoluble and soluble forms have resulted in the adoption of occupational limits of 9×10^{-11} μCi/ml and 3×10^{-10} μCi/ml, respectively. External radiation hazards have resulted in the adoption of a 50 rem/yr occupational exposure limit for both non-extremity and extremity dermal surfaces.

From animal studies it is known that uranium is chemically toxic to kidney tissues, and that if allowed to enter the bloodstream the element is preferentially deposited in that organ. The uranium is then eliminated via excretion in urine -- about 50 percent of the remaining burden every two weeks. For very short-term exposure conditions, it has been estimated that 60 mg U in the blood would be fatal to man (Luessenhop 1958).

Kidney damage by uranium can be detected from proteinuria, i.e., from protein released into the urine from kidney cells that have been killed. In one case of industrial exposure where the urinary excretion rate indicated about 4 mg in the blood, the exposure "seemed to produce albuminuria" (Eve 1964). The current standards of the Nuclear Regulatory Commission (NRC) and the American Conference of Governmental Industrial Hygienists (ACGIH) permit an inhalation exposure in a period of 40 hours or less that could introduce about 2.7 mg into the blood (10 CFR Part 20).

Although human kidney damage by uranium has not been clinically detected, early rodent studies revealed that more than 1 μg per g kidney maintained over an extended period does cause such damage (Voegtlin 1953). The current NRC inhalation standard was adopted from the 1959 ICRP recommendations, which set a nephrotoxic limit of 3 μg/g kidney maintained continuously over a working lifetime. Apparently the ICRP, in its extrapolation from rodent data to man,

gave considerable weight to the absence of clinically detectable effects among large numbers of early workers heavily exposed to airborne uranium (Hodge 1973). Current ICRP recommendations consider radiation only and do not include a uranium standard based on chemical toxicity (ICRP 1977; ICRP 1978).

More recent studies of dogs exposed to uranium revealed kidney damage at tissue concentrations a factor of 5 or more below the current nephrotoxic limit, confirming the rodent results and prompting the principal investigator to recommend lowering the limit to 0.6 μg U per g kidney (Morrow 1982). The NRC responded by requesting the BEIR-IV Committee of the National Academy of Sciences to review the necessity of lowering soluble uranium intake standards by a factor of 5; the resulting report was inconclusive (NAS 1988). The NRC then requested the ACGIH to consider whether its uranium standard should be revised, and this work is now in progress. In the interim, the NRC is retaining its standard based on 3 μg U per g kidney in the current major revision of 10 CFR Part 20.

Workers who have previously been exposed to uranium may be at greater risk in the event of subsequent kidney disease than unexposed workers, since it has been observed that a loss of up to 75% of kidney function can be clinically undetected. Subsequent kidney damage from disease can cause a severe adverse effect and prevent recovery, since there is no reserve kidney function remaining. Attending physicians would not likely suspect, or report, uranium involvement (USNRC 1988).

The current NRC inhalation limit for insoluble uranium compounds (based on the 1959 ICRP recommendations) is 0.2 mg/M^3 of air, averaged over one week, which is approximately equivalent to 8.6×10^{-11} μCi/ml for DU, or an intake of about 4×10^{-3} μCi/wk. These values are based on an assumed particle size distribution of 1μM AMAD. The recently promulgated Occupational Safety and Health Administration (OSHA) occupational limits for the soluble and insoluble forms of uranium are 0.05 mg/M^3 and 0.2 mg/M^3, respectively (29 CFR 1910.1000; January 19, 1989).

1.3.1.2 Tungsten

Tungsten is rapidly lost in the urine of experimental animals exposed to tungsten by ingestion, inhalation, or injection. Bone is the principal reservoir for tungsten that remains in the body. The tissue concentrating the next greatest amount of residual tungsten depends on the route of exposure, according to limited studies. Urinary excretion of tungsten predominates in experimental animals, but only trace quantities of tungsten are excreted in urine and feces from humans exposed to tungsten under occupational circumstances.

Neurophysiological processes are affected by tungsten in experimental animals. Pronounced disturbances of conditioned reflexes have been described in tungsten-exposed rats, while guinea pigs develop uncoordinated movement, sudden jumps, trembling, and breathlessness when exposed to sodium tungstate by gastric intubation. Epileptic-like seizures are produced when tungstic acid is applied to the cerebral cortex of experimental animals. Humans exposed to tungsten, in occupational circumstances, report increased headache, dizziness, nausea, and loss of the sense of smell.

Human occupational exposure to mixed tungsten dusts, containing cobalt, produce effects that are chiefly respiratory in nature, characterized by exertional dyspnea, coughing, and weight loss. These clinical signs sometimes progress to extrinsic asthma, diffuse interstitial pneumonitis, or fibrosis. Tungsten carbide dusts produce pulmonary fibrosis in animals and humans, but the cause of this condition is considered to be due to cobalt; the tungsten is believed to augment the cobalt effect.

Tungsten substitutes for and/or prevents the incorporation of molybdenum in the enzymes xanthine oxidase and sulfite oxidase in unborn rats when the mother is exposed to tungstate 20 days before birth. No observed deleterious effects have been noted in xanthine oxidase- and sulfite oxidase-deficient rats except that these animals are highly susceptible to bisulfite and SO_2 toxicity. Sulfite oxidase deficiency produces severe neurological abnormalities, biochemical alterations, and death in human infants.

The OSHA occupational limits for insoluble and soluble tungsten are 5 mg/M^3 and 1 mg/M^3 (29 CFR 1910.1000; January 19, 1989). For tungsten kinetic penetrators, the alloying metals are nickel (Ni), cobalt (Co) and iron (Fe) in the range 1% to 5%. The occupational limits for these metals are 1 mg/M^3 insoluble and 0.1 mg/M^3 soluble, 0.05 mg/M^3, and iron oxide fumes as Fe 10 mg/M^3, respectively (29 CFR 1910.100; January 19, 1989). ACGIH is currently recommending a 0.05 mg/M^3 TLV for both soluble and insoluble nickel. Ni and its compounds are carcinogenic by the inhalation route, and the published potency factor for Ni and its compounds for lifetime inhalation exposures is $[2.4 \times 10^{-4}$ $ug/M^3]^{-1}$ (USEPA 1989). This factor is based on standard particle size distribution and particle lung retention assumptions. Continuous exposure to a concentration of 4.2×10^{-6} mg/M^3 will result in a (*de minimus*) 10^{-6} lifetime increased cancer risk.

1.3.2 Potentially Significant Occupational, Military and Environmental Exposures Associated with the Generic Kinetic Penetrator-Related Military Life Cycle of DU and W Alloys

For the W military life cycle, potentially significant exposures occur at the same stages, activities and processes as for non-radiation exposures to DU, but for W there are no corresponding radiation exposures, and no pyrophoricity-related fires.

The potentially most significant non-radiation exposures to DU or W in its military life cycle as kinetic penetrator rounds occur during:

Occupational

- metal alloy manufacture
- penetrator machining
- waste collection, compaction, stabilization and containerization.

Military

- open air accuracy testing and area cleanup
- combat involving the use of armor-piercing ordnance
- post-combat reentry of ground troops into the battlefield.

Environmental

- open air accuracy testing with subsequent wind resuspension, leaching to ground water and runoff to surface water
- combat involving the use of armor-piercing ordnance.

The potentially most significant radiation exposures occur during:

Occupational

- waste management of slag from UF_4 reduction and cleaning of retorts
- quality control inspection of cast ingots, milling blanks, finished penetrators, and finished rounds
- recycling of flawed ingots, milling blanks, finished penetrators and finished rounds
- the loading and unloading of shipping crates containing finished or flawed inventory.

Military

- loading and unloading of ordnance supply lockers, magazines and ammunition racks
- proximity to ammunition racks during weapons use in combat readiness operations, particularly tank maneuvers
- post-testing cleanup of rapid fire target areas
- combat involving the use of armor-piercing ordnance
- post-combat reentry of ground troops into the impacted battlefield.

Environmental

- open air accuracy testing with subsequent leaching to ground water and runoff to surface water
- combat involving the use of armor-piercing ordnance.

1.4 COMPARISON OF HEALTH RISKS BETWEEN DU AND W AS KINETIC ENERGY PENETRATORS

The calculation of the health risks from exposures to DU in its military life cycle requires the adoption of appropriate exposure scenarios for the metal, radioactive daughter or alloys, as applicable. With respect to the exposure pathways, identified in Section 1.3, the actual exposures encountered in the occupational environment, representative worst-case exposures potentially encountered in the non-combat and combat military environments, and screening-level worst-case exposures were adopted for calculating an upper bound risk

estimate in the ambient environment impacted by non-combat testing activities and combat engagements.

Due to the constraints on data availability, information access, and time, an equivalent set of calculations for W were not conducted. Rather the focus of the discussion is on the intrinsic hazards of W. As a result, only a qualitative comparison of DU and W hazards is possible at present. However, quantitative comparisons can be made between kinetic energy penetrator-related health risks and those associated with exposures to background concentrations of uranium in soil, water, and sediment and natural background levels of alpha, beta, and gamma radiation from all sources.

1.4.1 Qualitative Comparison of DU and W Health Risks

The greater chemical and radiological toxicities of DU compared with W, when considered together with DU's fragmentation particle size PDF and pyrophoricity, results in a qualitatively greater DU inhalation risk for each activity in the military life cycle in which suspended particles are generated (e.g., milling of penetrators, testing-firing or combat). The soluble DU occupational limit is 0.05 mg/M^3 to protect from kidney toxicity. This creates an inhalation hazard differential between soluble DU and pure W of 20-fold, as the corresponding W occupational limit is 1.0 mg/M^3. Radioactivity of DU, although less than that of natural uranium, represents a hazard absent with W.

However, the presence of Ni metal in the tungsten alloy could potentially represent a significant hazard, since nickel and its compounds are considered carcinogenic by the inhalation route according to USEPA's Carcinogen Assessment Group (USEPA 1989). The higher vapor pressure of nickel than W at any given temperature may result in a disproportionate concentration of Ni vapor in the occupational air where W alloy is being melted or heat-treated in kinetic energy penetrator manufacturing operations.

For the non-occupational military and ambient environments, the concentration of nickel particles in the air will be determined by the degree of fragmentation of the W alloy kinetic energy penetrators. The air concentration of nickel refinery dust corresponding to a *de minimus* 10^{-6} lifetime increased

cancer risk is 4.2×10^{-6} mg/M^3, when exposure occurs continuously for a 70 year lifetime, about two and one-half times the corresponding value for DU. If Ni comprises 5% of the W alloy used in kinetic penetrators, then the concentration of kinetic penetrator fragmentation aerosol in the ambient environment corresponding to a *de minimus* 10^{-6} lifetime increased cancer risk is 8.4×10^{-5} mg/M^3.

Although the above comparative evaluation may be compelling on its face, where DU is involved, the occupational reality is that exposure to DU is to be minimized to the extent feasible by "as low as reasonably achievable" (ALARA) practices. In the DU manufacturing industry, it is estimated that institution of ALARA practices results in exposures that average 5 to 10 percent of occupational limits.

Despite the above caveat, in qualitative terms, the risk per unit exposure and the inhalation exposure per unit activity in the military life cycle of a kinetic penetrator are greater for DU than W based on currently available information which assumes the effects of radiation are linear, where the effects of chemical toxicity has a threshold.

The question then becomes one of the significance of the health risks attributable to the greater health hazards and inhalation exposure potential of DU versus W relative to: 1) lifetime increased cancer risks routinely accepted in non-military occupational environments; and 2) background concentrations of uranium in various media and background lifetime increased cancer risks associated with natural background radiation.

1.4.2 Quantitative Comparison of DU Health Risks in Occupational, Military and Ambient Environments Versus Background Risks

1.4.2.1 Risk Perspective

Before summarizing the results of the quantitative analyses of risk performed in this report, it is appropriate to place the calculated risks in perspective. The lifetime increased cancer risk from all background radiation sources has been calculated to be about 2×10^{-3}. The U.S. Occupational Safety and Health Administration (OSHA) routinely establishes occupational limits for

carcinogens with lifetime increased cancer risks in the range 10^{-4} to 10^{-2}. The U.S. Environmental Protection Agency (EPA) has proposed as a matter of policy to establish Superfund site cleanup target levels based on *de minimus* risks in the range 10^{-7} to 10^{-4}, with 10^{-6} usually triggering Agency concern. However, EPA's indoor radon concentration limit is equivalent to a lifetime increased cancer risk of about 10^{-2}. Many states have adopted *de minimus* lifetime increased cancer risks for surface waters and ground waters of 10^{-5} and 10^{-6}, respectively, rationalizing the difference in the degree of health protection in terms of the slower rate of self-cleansing of ground-water systems.

Although the radiation dose-response models for lifetime increased cancer risk are derived from epidemiological data, it should be kept in mind that the lifetime increased cancer risk estimates contained in this report are just that, estimates. Strict comparison of these estimated risks to real risks quantified in actuarial tables should be avoided. The risk estimates contained in this report may overestimate the risk in certain circumstances, perhaps significantly so. In other circumstances the risks may be underestimated, but it is less likely that they will be significantly underestimated, because of two conservative practices adopted, particularly for the military and public exposures: 1) The high dose dose-response relationship for lifetime increased cancer risks is used, although low dose, chronic exposures are encountered. This may provide a margin of safety of about 2.5 times. 2) The exposures have been intentionally overestimated as representative worst case, improbable worst-case, or impossible worst-case, in order to bound the risk quantification problem. Where such extreme exposure estimates do not produce unacceptable risks, one should be confident that more reasoned, more time-consuming and data intensive analyses would result in even lower estimates of risk. Where such extreme exposure estimates do result in unacceptable risks, more reasonable assumptions are called for. Ideally, relevant source-, species- and site-specific data will be available to conduct such analyses.

1.4.2.2 Occupational Exposures to DU

Workers exposed to DU in connection with the production of projectiles are subjected to potential radiobiological and chemical toxicity risks. In this report a somewhat complex analysis is performed to evaluate the magnitude of

those risks. The results are presented in the following table. As shown, no radiation-induced cancer fatalities or chemical toxicity effects are expected among the assumed 260-person workforce.

TABLE 1-5 DU RISK EVALUATION RESULTS

Exposure Mode	Risk (fatalities per person)
Inhalation:	
Chemical Toxicity	negligible
Radiobiological Effects	0 to 2 x 10^{-3}
External Photon Irradiation:	
Extremity Bone	0 to 0.6 x 10^{-4}
Skin	0 to 1.4 x 10^{-4}
All Other Organs	0 to 3 x 10^{-4}
Total	0 to 2.5 x 10^{-3}

For this analysis it is assumed that the exposure period is 20 years. The radiobiological risk is smaller for individuals who remain in this line of work for a shorter period of time. The risk estimators employed are the most recent available from the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1988). Negligible chemical damage to the kidneys is assumed because the radiation limit for uranium in kidney tissues limits the uranium to a factor of 5 lower than currently permitted by the American Conference of Governmental Industrial Hygienists (ACGIH) and Nuclear Regulatory Commission (NRC) standards.

The 1990 Report of the National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR V) provided new estimates of the risks from exposure to ionizing radiation based on the epidemiological estimates derived largely from the Japanese A-bomb survivors who were exposed to extremely high radiation doses and dose rates. The BEIR V estimates were not greatly different from those by UNSCEAR (1988). However, UNSCEAR and other expert groups have recognized the need to provide a dose and/or dose rate effectiveness factor

to these estimates for application to dose below about 1 to 10 rem, and for lower dose rates. While the details are provided in Appendix A, it is clear that any reasonable correction of the BEIR V risk estimators for use at low doses and dose rates will not result in a significantly different estimate of risk than used in this report.

1.4.2.3 Military Exposures to DU

To quantify the non-combat and combat health risks to military personnel associated with DU exposures in its military applications or a kinetic penetrator, representative worst-case exposure scenarios were constructed from empirical data on DU kinetic energy penetrator fragmentation efficiencies, fragment distribution patterns, and particle size distributions. For military personnel the chemical toxicity threshold dose is not reached. All combat-related internal and external radiation risks were in the range 10^{-7} to 10^{-5}. The most significant external radiation exposure occurs during the loading and unloading of ammunition lockers, with a lifetime increased cancer risk to the extremities as high as 3×10^{-4} resulting from a worst-case, 20-year exposure. Even minimal safety precautions would reduce this risk to levels well below those tolerated in most occupational environments.

1.4.2.4 Public Exposures to DU

Public exposures to DU associated with its use as a kinetic energy penetrator can occur as a result of the transport of DU particles and contaminated soil particles from the test range due to wind erosion, precipitation runoff, or leaching to groundwater.

Inhalation risks to the public are minimal from enclosed and open air testing activities, but the practice of leaving accuracy testing penetrator fragments in place on the range has been suggested as representing an unacceptable risk to the public health due to their solubilization in rainwater, with subsequent accumulation and leaching to groundwater and transport to a drinking water well. However, when realistic transport assumptions are employed, the drinking water health risks fall below the de *minimus* 10^{-6} risk level. Improved housekeeping practices involving retrieval of kinetic penetrator fragments will further reduce the potential health risks from this pathway.

1.4.3 Preliminary Conclusions

These preliminary conclusions are drawn from the information reviewed to date as identified in the bibliography and the above-described occupational, military, and public exposure scenarios.

Lifetime increased cancer risks for military personnel associated with the testing of DU kinetic penetrators calculated from a highest credible exposure scenario may exceed those associated with natural background radiation under some circumstances but not significantly so. These risks would not be inconsistent with those routinely accepted in other non-military occupational settings.

Where the chemistry of the soil in the vadose zone and the properties and chemistry of the substrate in the saturated zone favor DU solubilization, transport to a hypothetical drinking water well 5 km distance from the test site could exceed the *de minimus* 10^{-6} lifetime increased cancer risk level by about two orders of magnitude. Under more realistic circumstances, the impacts on ground water are likely to be *de minimus*.

This risk assessment assumes that exposures within the DU industry average 5-10% of current NRC regulatory limits. Actual exposures could be higher, resulting in changes to the quantitative assessments provided.

New regulations are expected to be implemented by NRC, and the models on which these new regulations are based have been incorporated into this document. Interpretations of risk are therefore complicated by the presence of current acceptable standards and standards which have not been implemented to date.

When ALARA practices are taken into account, the occupational health risks associated with DU radiation exposure, although potentially higher than background radiation risks, are not inconsistent with occupational health risks associated with occupational limits for other carcinogens.

Against the hypothetical lifetime increased cancer risks of exposure to DU must be weighed the elevated risks of lung disease among tungsten workers,

particularly in the presence of nickel or cobalt metal, and the observed incidences of cancers among nickel workers.

2. OCCUPATIONAL, MILITARY AND PUBLIC HEALTH HAZARDS AND EXPOSURE PATHWAYS ASSOCIATED WITH THE KINETIC PENETRATOR LIFE CYCLE

The activities and processes associated with the kinetic penetrator life cycle are discussed below along with the discussion of the health hazards associated with depleted uranium and tungsten.

2.1 DEPLETED URANIUM

2.1.1 Processes and Exposure Pathways

2.1.1.1 Manufacture of Kinetic Penetrator Projectiles

Two DU penetrator production sites were visited during this study. Manufacturing processes were observed and investigated. Due to the proprietary nature of some of these processes, manufacturing descriptions are not included in this section.

2.1.1.2 Activity: Assembly of Armor-Piercing Munitions

The projectiles are transported to the assembly facility in appropriately labelled containers meeting applicable DOT and NRC specifications for the transport of low-level radioactive solid materials. The projectiles containers are unloaded and either stored or transported directly to the assembly area. Projectiles received from the manufacturer are inspected prior to cleaning. Flawed projectiles are returned to the manufacturer for remelt. The projectiles are then inserted into a slotted steel base that forms the top of the cartridge filled with the explosive charge. Next the projectile and cartridge are enclosed in an aluminum cowling or "windscreen" that is joined to the steel base with a series of plastic rings that are inserted into grooves encircling the steel base and the aluminum cowling. The exact configuration of the armor-piercing round is classified information. Flawed rounds are disassembled. If the projectile is intact, it is recycled to the assembly process. If the projectile has been damaged during assembly, it is recycled to the manufacturer for remelt. Finished rounds are packed in crates for shipment to Army ordnance supply centers for testing and subsequent disbursement to Army facilities.

Inhalation exposure to DU occurs during the unloading and cleaning of the projectiles when surface mechanical ablation of the surface oxide coating can generate suspended particles and in the collection, compaction, and containerization of solid wastes generated from floor sweepings and HEPA filters. These exposures must be considered of far less quantitative significance than those experienced in the manufacture of DU kinetic penetrator projectiles, however. Potentially significant external exposure to DU radiation occurs during the unloading of projectile shipments from the manufacturer, inspection of projectiles, and in the mating of cartridge and projectile. Personnel involved in maintenance processes in the vicinity of projectile or finished round storage areas may also experience potentially significant radiation exposure.

2.1.1.3 Testing

Four types of testing of armor-piercing ammunition occur: ordnance quality control, armor-piercing efficacy, accuracy, and performance.

Random Testing Ordnance Quality Control

The typical modern testing facility consists of an enclosed target area with a small aperture for the entrance of the kinetic penetrator shell. Negative pressure is maintained by high velocity vent fans achieving 3,000 cubic feet per minute of air flow. Prior to discharge to the ambient environment, air within the target area enclosure is passed through a three-stage filter, each stage composed of four fiber glass pads of 2-5 inches, six inches and 12 inches thickness, respectively. Each filter cell is certified by its manufacturer to achieve at least a 99.97 percent filter efficiency using the dioctyl phthalate droplet test.

The armor-piercing ammunition is fired in bursts ranging in duration from a fraction of a second to six seconds at a rate of 2100 or 4200 shots per minute at a butt 300 feet away consisting of roughly 360 cubic yards of sand that has been pre-wetted to reduce the generation of suspended particles. Upon impact the kinetic penetrator projectile disengages from the aluminum windscreen due to the greater drag of the latter than the former. The projectile's surface ablates as it passes through the sand pile. As the projectile begins to flatten the

collision cross-section grows, increasing the rate of flattening. At some point the rate of transfer of momentum to the sand becomes high enough to shear the metal, and fragmentation occurs. Each fragment then undergoes the processes of ablation, flattening and fragmentation until the momentum of the projectile is spent. Due to the high rate of conversion of kinetic energy to heat as the projectile strikes and passes into the butt, the small fragments are likely to ignite spontaneously, particularly those reflected from the surface of the butt. Due to the brittle nature of the crystalline structure of the DU particles so generated, the resulting DU particles readily crumble into still finer particles (USAF 1978).

The actual particle size distribution function of kinetic penetrator fragments generated in the above described testing is not reported in the literature reviewed. However, recovery of the larger fragments from the sand butt is effected by sifting the sand through a 1/2 inch mesh screen which yields about 50% of the mass of penetrators fired at the butt.

Water from the sand pile-wetting operation drains beneath the sand pile into a pipe that collects the drainage and conveys it to a 55-gallon barrel containing a mixture of clay and sludge that effectively immobilizes any DU that may have been lost from the butt due to leaching.

Air monitors are placed inside the test structure to assess air quality.

Armor Penetration Efficacy Testing

The armor-piercing rounds are fired at test targets of various thicknesses at various distances and angles to evaluate military performance. The targets include rectangular pieces of military armor plate. The target plate is typically placed near the front of the testing enclosure. The intended point of impact is surrounded by a steel culvert pipe 1 meter in diameter and 10 meters long. This piece functions to capture reflecting projectile fragments. Behind the target towards the back of the enclosure is a 75 cubic yard "bullet catcher" sand pile butt (Harris 1988).

Upon impact with the armor plate the kinetic penetrator projectile fragments can be divided into two categories: those that penetrate the armor and those that are reflected from the armor. Both fragment categories involve pieces of various size, from large pieces on the order of centimeters down to micron size. Fragmentation when armor plate is the target is far greater than when sand alone is the target. Most of the fragments spontaneously ignite due to the pyrophoric nature of uranium metal and the extreme flash temperatures generated on impact of 3037° to 3093° C over the entire range of impact velocities from 4010 to 5560 feet per second (PATEC-TR-157-70). The particles result primarily in UO_2 and U_3O_8. Due to the extremely high density of U and its oxides, the penetrator fragments and smoke particles rapidly settle in the immediate vicinity of the target area. The walls and concrete pads under the target area enclosure become contaminated with the uranium and uranium oxide particles.

Following a test firing series, the target is inspected. Contaminated armor is cleaned and sold for scrap. Butt sand is sifted to remove large fragments and reused, generally three times, until too pulverized to be of further use. HEPA filters are replaced when the pressure drop across the stages is greater than 3 torr. Wasted sand, structure sweepings, and HEPA filters are containerized for disposal as low-level radioactive waste.

Accuracy Testing

Accuracy testing occurs in an open firing range under limited ambient weather conditions. Under dry grass conditions, range fires can be started by DU particles that spontaneously ignite during projectile fragmentation. Where projectile fragments are being collected, projectile fragments from the target area are located using magnetometers and retrieved directly or using manual soil moving and sieving equipment. Fragments are collected, compacted and containerized for off-site low-level radioactive waste disposal. Alternative waste management options include recycling fragments to the remelt step or on-site disposal.

2.1.1.4 Recycling of Kinetic Penetrator Projectile Fragments

Although recycling of projectile fragments is not now a significant component of the military life cycle of kinetic penetrators, it has been proposed that recycling be adopted to reduce the generation of low-level radioactive waste as well as to conserve a limited strategic raw material. Increased collection efficiencies will probably have to be achieved with existing or new technologies and methodologies in order to justify the reallocation of human, physical, and fiscal resources to such an effort. The actual technologies to be used in collecting the fragments may involve more efficient sifting of soils and sand butts than is presently achieved. The points of reentry of recycled fragments into the military stage of the kinetic penetrator life cycle are identified in the activities above.

Once collected, the recycled fragments must be pre-cleaned, stored, shipped, and cleaned prior to reentering the kinetic penetrator or other DU product manufacturing sequence.

Occupational, military, and environmental exposures from fragment recycling-related operations are likely to be commensurate with those associated with present-day post-test sifting of sand butts. However, pre-cleaning and cleaning of recycled fragments represent two additional processes in the military life cycle of the kinetic penetrator, increasing the number of individuals exposed in military and occupational environments.

2.1.1.5 Combat-Ready Ordnance Supply

Once a production lot meets Army ordnance quality control specifications, the armor-piercing munitions are distributed to Army ordnance supply centers which in turn further distribute the ammunition to military base ordnance supply lockers and thence combat-ready weapon systems. Such weapons include ground-based and air-based anti-aircraft and anti-tank guns. Wastes generated during combat-readiness operations and actual combat situations include kinetic penetrator fragments, contaminated munitions components (e.g. tail fins, aluminum windscreens) and dud and misfire rounds. Presumably post-combat restoration of battlefields, if required, will include collection of penetrator fragments,

sifting of highly contaminated soils, impact site decontamination and related waste disposal activities.

Highest exposures of Army personnel to external DU radiation can occur during the loading and unloading of gun ammunition racks and during combat-readiness training, maneuvers, routine patrols and actual combat situations. Additional exposures to DU will probably only occur during combat when vehicles are crossing terrain impacted by armor-piercing projectiles or fragments and during post-combat battlefield restoration. If the same occupational safety and health precautions are taken by military personnel during post-combat battlefield restoration operations as during post-testing cleanup of test areas, internal and external exposure to DU radiation should be minimized.

2.1.1.6 Recycling to Non-Military Applications

The recycling of armor-piercing munitions involves recall of the munitions from points of disbursement; collection, containerization, and shipment to the assembly facility; storage; disassembly; recycling or wasting of kinetic penetrators; and low-level radioactive waste collection, compaction, containerization, shipment, and disposal. In addition to DU-related solid wastes, low level waste also consists of non-penetrator components of the armor-piercing munitions (e.g., aluminum windscreens) that have become contaminated as a result of contact with the penetrator.

An alternative method is destructive firing, in which the ordnance is fired into a sand butt "bullet catcher" to end its military career. Fragments sifted from the sand butts would then be recycled into non-military applications, and the contaminated sand piles, cleaning supplies, and HEPA filters would be disposed of as a low-level radioactive waste.

Occupational, military and, environmental exposures associated with the disassembly alternative should be roughly commensurate with those associated with armor-piercing munitions manufacture; while exposures associated with the destructive firing alternative should approximate those associated with present-day ordnance quality control testing.

2.1.1.7 Decommissioning

Manufacturing, storage, testing, and waste management equipment and edifices must be decommissioned prior to reentering the non-military economy, being mothballed for future military use, or dismantled for recycling and scrap. Decommissioning involves sampling to define the nature, magnitude, and spatial heterogeneity of contamination; cleanup; equipment recycling or dismantling; edifice recycling or dismantling; and waste collection, compaction, containerization, shipment, and disposal.

Options for decommissioning include disposal of contaminated buildings and equipment by burial; partial decontamination, disassembly and either disposal as scrap or full decontamination for reuse; mothball for future use; or full decontamination and reuse of site, buildings and machinery.

Decommissioning processes (after NSMC 1988) could include surface decontamination by abrasives, followed by dry vacuuming of surfaces; solvent paint stripping or degreasing (including ultrasonic agitation); wire brushing; steam jet cleaning; reactive chemical surface application or soaking; electropolishing; and others, singly or in various combinations, followed by area washdown with high velocity hoses; collection of wastewater for filtration prior to discharge to sewer system; and disposal of wastewater filtrate, sand, paint strips, grinding dust and HEPA filters from vacuums as low level radioactive solid waste. Prior to certification of decontamination, all structures, machinery and equipment are tested for radioactivity above background.

Contaminated soil remediation could involve excavation of soils down to DU contamination profiles equal to background levels, which may approximate 0.15 meters.

Proper attention to the occupational and environmental safety procedures used in the cleanup of test firing areas should minimize occupational exposure to DU and DU-related external radiation. To minimize the exposure of downwind populations, decommissioning activities involving the dismantling or razing of structures will be assumed to be limited to favorable meteorological conditions.

2.1.1.8 Remediation

Where on-site disposal of remelt slag and DU oxide wastes has occurred historically at penetrator manufacturing facilities, the quality of soils, ground water, and nearby surface waters may have been affected. Under such circumstances, environmental concerns could be present. However, such practices are no longer occurring and thus should not be considered inherent to the life cycle of DU penetrators in the future.

With the enclosure of quality control and armor piercing efficacy test areas, contamination of surrounding soil, underlying ground water, and nearby surface water sediments should be eliminated. Open range testing will result in kinetic penetrators being dispersed on the range with some potential for oxidation and dispersion in the range soils.

Restoration activities include site surveys; soil, ground-water and sediment sample collection; sample collection-related waste collection, compaction, containerization, sampling, and analysis according to the protocols set forth in the regulations promulgated under the Atomic Energy Act. Uranium source materials and byproducts are exempted from the waste management site closure, remediation and monitoring requirements of the Resource Conservation and Recovery Act of 1976 and the Hazardous Waste Act Amendments of 1984. However, for abandoned non-DOD waste disposal sites, the site restoration requirements of the regulations promulgated under the Superfund Amendments and Reauthorization Act of 1986 or equivalent state requirements will apply.

Subsequently, when full-scale soil and sediment excavation and ground-water withdrawal and treatment begin, waste management requirements change.

As with decommissioning activities, proper attention to occupational and environmental safety and health protection procedures will limit occupational and public exposure. However, some windborne and waterborne redistribution of DU can be expected in soils and sediments, respectively, during excavation activities. Treatment of contaminated ground water and sediment dewatering wastewater via sand filtration and then ion exchange resin columns will probably be sufficient

to reduce the discharge of soluble and particulate DU well below levels of environmental or public health concern. Solid residues from filtration systems will probably have to be disposed of as a low level mixed radioactive waste.

For Department of Defense facilities, the DoD's Installation Restoration Program (IRP), and the policies and guidance published to implement it, govern site remedial investigations, the nature and degree of cleanup, waste management practices, etc.

2.1.2 Toxicity and Health Effects of Depleted Uranium

2.1.2.1 Radiological Toxicity From Inhalation

Uranium is a naturally radioactive element and is found in nature in equilibrium with a large number of radioactive daughter products, including radium and radon. During the processing of uranium ore the daughter products are removed, leaving three uranium isotopes distributed as indicated in Table 2-1 below. When this uranium is subjected to the U-235 enrichment process, the

TABLE 2-1. EFFECT OF U-235 ENRICHMENT ON THE ISOTOPIC DISTRIBUTION OF DU

Isotope	Natural U Percent By Weight	Depleted U Approximate Percent By Weight	Depleted U Typical Percent By Activity
U-238	99.283%	99.8%	77.3%
U-235	0.711%	0.2%	1.0%
U-234	0.005%	-0.0015%	21.7%

residue, called depleted uranium (DU) has an activity distribution similar to one shown in the fourth column of the Table 2-1. The specific activity is near 4.3 x 10^{-7} Ci/g, as compared with 6.77 x 10^{-7} Ci/g for the natural uranium isotope mixture.

Immediately following separation from its daughter products, the radiation emitted by uranium is almost entirely alpha. Alpha radiation is considered to be a factor of 20 more efficient at causing health effects than beta and gamma radiation, provided that the alpha emitter is located inside the body (ICRP 1977). As the uranium daughter products begin to reappear, beta and gamma radiation require attention. For example, the ultimate dose rate from beta and gamma radiation at the surface of a uranium slab is about 240 millirad per hour. With regard to internally deposited uranium, however, alpha radiation continues to almost completely dominate the magnitude of the radiation dose delivered. Beta radiation from uranium outside the body can penetrate to the basal cell layer of the skin, the gamma radiation can also penetrate to the internal organs. All three cases create a dose-dependent cancer risk.

From past experience with radium dial painters, early medical uses of radioactivity, and exposures of uranium miners to radon progeny, it is known with virtual certainty that alpha radiation is carcinogenic when high doses are delivered to a sufficiently large number of cells in a radiogenic organ. While no cases of cancer caused by internally deposited uranium are on record, it is prudently assumed if alpha particles from radium and radon progeny can cause cancer, alpha particles from uranium could do the same if the doses were comparable. The specific activity of radium (1 Ci/g) is about 1.5 million times higher than natural uranium, so that fewer grams of radium need be inhaled to deliver a given dose; also, the spatial distribution of dose to affected cells from deposited activity is radically different. Of course, far more gamma radiation accompanies the radium disintegrations. Animal experiments with alpha "hot particles" as well as other radiobiological experiments indicate that local protective mechanisms against cancer cells can be adversely affected where larger volumes of tissue are irradiated. Thus the extrapolation of radium risk to uranium risk on the basis of dose may be conservative. The only radium dial painters and uranium miners who experienced cancer received very high doses. Regulatory standards today limit exposures to considerably lower levels.

The Nuclear Regulatory Commission (NRC) is in the final stages of a rulemaking action which will adopt the current recommendations of the ICRP (ICRP 1977, ICRP 1978), including a recommendation to lower the annual limit on intake

for insoluble, airborne uranium by a factor of 6. This very substantial decrease is primarily the result of changes in the models used by the ICRP to calculate radionuclide intake limits. For example, for the old standards it was assumed that insoluble compounds would be eliminated from the lung with a half-life of 120 days, i.e., every 120 days 50% of the remaining burden would leave the pulmonary region of the lung; for the new standards a 500-day half-life is assumed, and other changes in the inhalation model were made. Also, for the old standard it was assumed that alpha radiation is a factor of 10 more carcinogenic than gamma radiation; for the new standard a factor of 20 is assumed. Two important improvements were made that had little or no effect on the Class Y uranium standard: (1) for the old standard the risk to organs other than the lung was ignored; for the new standard the risk to all significantly affected organs is accounted for; (2) the old model ignored radiation delivered to an organ by radionuclides located in other organs; this omission is corrected in the new model.

The old and new occupational annual intake limits for insoluble compounds of uranium are shown in Table 2-2. It is permissible to exceed the concentration values as long as the intake limits are not exceeded. Because of roundoff error, the reduction factor is shown as 5 for the concentration value but 6 for the intake limit. The tabular entries are also applicable to any isotopic distribution -- depleted, natural, or any degree of U-235 enrichment.

TABLE 2-2. OCCUPATIONAL INHALATION STANDARDS FOR CLASS Y URANIUM

(Current 10 CFR 20) (Insoluble) *		(Proposed 10 CFR 20) (Class Y) **	
Average Concentration (μCi/ml)	Intake (μCi/yr)	Average Concentration (μCi/ml)	Intake (μCi/yr)
1×10^{-10}	0.25	2×10^{-11}	0.04

* Based on equilibrium conditions which deliver a committed dose equivalent of 15 rem/year to the lungs.

** Based on equilibrium conditions which deliver a committed effective dose equivalent of 5 rem/year to the lungs.

Under the assumptions used for the old limit, 0.25 μCi of uranium inhaled annually at an average concentration of 1×10^{-10} μCi/ml of air would maintain 16 nanocuries in the pulmonary region of the lung, distributed uniformly. (Uniform distribution maximizes the cancer risk by maximizing (1) the number of transformed cells and (2) adverse effects on surrounding protective cells.) The annual dose equivalent would be 15 rem. To the extent that the cancer fatality risk coefficient for the lung given in ICRP-26 (2×10^{-5} per rem) is applicable, the risk induced each year would be 3×10^{-4}, or a 50-year working lifetime risk of 1.5×10^{-2}. The last number means that 1.5% of a large number of workers exposed at the intake limit for their entire careers would be estimated to die of uranium-induced lung cancer. Using the new UNSCEAR (1988) risk estimate, 1.5×10^{-4} cancer deaths per million person-rem, the lifetime risk estimate is about 11 percent if the dose is large and delivered at a high dose rate. For occupational exposure conditions, the risk is reduced by a factor of 2.5 to 4.5 (RERF 1988). These estimates ignore any risk caused by the transfer of uranium from the lung via the blood to other organs. Note that use of the word "insoluble" has been discontinued in favor of the term "Class Y", where Y is indicative of retention in the lung for years.

Under the assumptions used for the new limit, 0.04 µCi of Class Y uranium inhaled annually at an average concentration of 2×10^{-11} µCi/ml of air, with immediate deposition in the lung and subsequent/eventual depositions in the kidney, bone, and other organs, induce the same overall cancer fatality risk as a dose equivalent of 5 rem delivered uniformly during the year to every organ of the body by an external source. To the extent that the cancer fatality risk coefficient (1.25×10^{-4} per rem[1]) given in ICRP-26 for external exposure of this type is correct, each annual intake of 0.04 µCi would induce a cancer fatality risk of 6.25×10^{-4}, or a 50-year working lifetime risk of about 3×10^{-2}, or 3%.

---

[1]The ICRP-26 summation is actually 1.65×10^{-4}, including 4×10^{-5} for very serious genetic effects. Since no human genetic effects have been observed, consideration of this risk is being discontinued in the risk distribution system (weighing factors) [UNSCEAR, 1988] and is not included here. The effect of this change is redistribution of the total cancer risk among the radiogenic organs, which does not change the basis of 5 rem per year from external sources used here for making uranium intake risk estimates.

If 3×10^{-4} per rem is used (Appendix A), the lifetime risk estimate becomes about 7%, including a correction for higher risks at high dose rates.

These occupational fatality risks may sound unreasonably high to the reader; and, of course, they are. In radiation protection, the limits are not implemented alone, and actual risks are not proportional to the limits at all, but to the average annual dose received. The As Low As Reasonably Achievable (ALARA) concept is coupled with the limits to assure an adequate degree of safety while at the same time providing useful and safe operational flexibility. Under the ALARA concept cost-effective exposure-reduction techniques are employed which maintain the average annual exposure at a relatively small fraction of the limit. For example, in the nuclear fuel fabrication industry uranium intakes average 10 to 20% of the old (but still in force) limits. In the DU projectile industry, the intakes are estimated at less than 10%. The NRC includes implementation of the ALARA concept, and will not accept mere compliance with its limits.

The current NRC standard (ICRP 1959) and proposed NRC standards (ICRP 1977) occupational intake limits for soluble compounds of uranium are shown in Table 2-3. The current NRC limits are based on chemical toxicity to the kidney.

TABLE 2-3 OCCUPATIONAL INHALATION STANDARDS FOR CLASS D URANIUM

	Current 10 CFR 20 Old (Soluble)		Proposed 10 CFR 20 New (Class D)	
Isotopes	Average Concentration (μCi/ml)	Intake (μCi/wk)	Average Concentration (μCi/ml)	Intake (μCi/yr)
U-238	7×10^{-11}	0.0034	6×10^{-10}	1
U-235	5×10^{-10}	0.024	6×10^{-10}	1
U-234	6×10^{-10}	0.029	5×10^{-10}	1
U-nat	1×10^{-10}	0.005	5×10^{-10}	1
DU	9×10^{-11}	0.0044	5×10^{-10}	1

The new ICRP limits are based on the non-stochastic radiation effects on the bone (surface); they will not be adopted by the NRC because the chemical toxicity limits (for kidney damage) are lower. However, for low exposures below the bone and kidney damage thresholds, the cancer risk (if any) is the only risk. The DU values are slightly lower than the U-natural values because chemical toxicity is proportional to the mass rather than the activity, and for the same mass less activity is present in DU. The chemical toxicity risk is discussed in Section 2.1.2.2. The term "soluble" has been discontinued in favor of the term "Class D", where D signifies retention in the lung for a period of days. The ACGIH threshold limit value for chemical toxicity is 0.2 mg U per m^3 of air, averaged over a 40-hr workweek. This standard is also given in the current NRC regulations (10 CFR Part 20). An annual intake of 2 µCi of Class D uranium of any isotopic distribution produces a theoretical lifetime cancer fatality risk of about 7 percent, equal to that of a uniform 5-rem per year dose equivalent to the entire body (ICRP 1978). Thus, a 1 µCi intake is associated with a lifetime risk of about 3.5 percent.

In 1977 the ICRP adopted an intermediate solubility classification called "Class W", where W signifies retention in the lung for weeks. The ICRP annual intake limits for uranium Class W compounds are given in Table 2-4. Each annual intake of 0.8 µCi of Class W uranium, of any isotopic distribution, all organs considered, is estimated to induce the same cancer fatality risk each year as given above for 0.04 µCi of Class Y uranium, as well as the same lifetime risk of 7%.

TABLE 2-4. OCCUPATIONAL INHALATION STANDARDS FOR CLASS W URANIUM

Isotopes	Average Concentration (µCi/ml)	Intake (µCi/yr)
U-238	3×10^{-10}	0.8
U-235	3×10^{-10}	0.8
U-234	3×10^{-10}	0.7
U-nat	3×10^{-10}	0.8
DU	3×10^{-10}	0.78

From the discussion to this point it is evident that the degree and nature of the risk associated with uranium exposure under normal working conditions, even at the regulatory limit, is highly dependent upon the solubility classification of the uranium compound involved. These theoretical risks are summarized in Table 2-5.

TABLE 2-5. OCCUPATIONAL RISK FROM THE INHALATION OF DU AT RECOMMENDED LIMITS USING ICRP-26 RISK COEFFICIENTS FOR FATAL CANCER

	Annual Limit on Intake (μCi)	Kidney Damage Risk	Lifetime Fatal Cancer Risk
Class D* (kidney damage)	0.22	None if the nephrotoxic limit is ≤ 3 μg U/g kidney.	0 to 0.3%
Class D	1	Weekly limit could be exceeded by a factor of 227 in worst case. Likely fatal.	0 to 1%
Class W	0.8	None unless the radiation protection standard is considerably exceeded.	0 to 3%
Class Y	0.04	None unless the radiation protection standard is considerably exceeded.	0 to 3%

*The weekly intake limit has been multiplied by 50 for purposes of annual comparison only. Whereas the ALIs for protection against cancer have an annual time restriction, only 0.0044 μCi of Class D uranium may be inhaled in 1 week.

NOTE: Because of the most recent information from the epidemiological study of the atomic bomb survivors, the RERF, UNSCEAR, ICRP, NCRP, EPA and NRC are now using risk coefficients higher than the former ICRP value of 1.25×10^{-4} mentioned above. In Appendix A this situation is reviewed, and a justification is given for using 3×10^{-4}, raising the lifetime risk for depleted uranium exposure from 3% to 7%.

The lifetime fatal cancer risk given for Class D uranium (kidney damage) is based on exposure at the limit established for chemical toxicity as opposed to the maximum exposure which would be allowed based on the radioactivity. Applying the radioactive limits results in a lower risk.

2.1.2.2 Chemical Toxicity From Inhalation

From animal studies performed primarily at the University of Rochester, it is known that uranium is chemically toxic to kidney tissues, and that if allowed to enter the bloodstream the element is preferentially deposited in that organ. The uranium is then eliminated via excretion in urine, about 50% of the remaining burden every two weeks. For very short-term exposure conditions, it has been estimated that 60 mg U in the blood would be fatal to man (Luessenhop 1958). Seven workers are reported to have experienced uptakes to the blood of 5 to 12 mg U in periods of 7 minutes or less, with no clinically observable effects (Wing 1965). Kidney damage by uranium can be detected from proteinuria, i.e., from protein released into the urine from kidney cells that have been killed. Four people were administered 10.8 mg U each with no subsequent proteinuria or other symptoms (Hursh 1969). It has been reported that the ingestion of up to 1400 mg U, under certain conditions, is known to be safe. Such an intake could place 14 mg or more into blood (Spoor 1968). At one industrial plant more than 50 cases were recorded of urinary uranium excretion rates which indicated about 2 mg U in the blood, with no evidence of kidney damage (Wing 1965). However, in one case where the urinary excretion rate indicated about 4 mg in the blood the exposure "seemed to produce albuminuria" (Eve 1964). The current standards of the NRC (USNRC 1989) and the ACGIH permit an inhalation exposure, in a period of 40 hours or less, which could introduce about 2.7 mg into the blood (10 CFR Part 20).

Although human kidney damage by uranium has not been clinically detected, early rodent studies revealed that more than 1 µg U per g kidney maintained over an extended period does cause such damage (Voegtlin 1953). However, the NRC inhalation standard was adopted from an ICRP recommendation (ICRP 1959) which is based on a nephrotoxic limit of 3 µg per g kidney maintained continuously for a working lifetime. Apparently the ICRP, in its extrapolation from rodent data to man, gave considerable weight to the absence of clinically detectable effects

among large numbers of early workers heavily exposed to airborne uranium (Hodge 1973). Current ICRP recommendations consider radiation only and do not include a uranium standard based on chemical toxicity (ICRP 1977, ICRP 1978).

More recent studies with dogs exposed to uranium, performed at the University of Rochester under NRC funding, revealed kidney damage at tissue concentrations a factor of 5 or more below the current nephrotoxic limit, confirming the rodent results and prompting the principal investigator to recommend lowering the limit to 0.6 μg U per g kidney (Morrow 1982). The NRC responded by requesting the BEIR-IV Committee of the National Academy of Sciences to review the necessity of lowering soluble uranium intake standards by a factor of 5; the resulting report was inconclusive (NAS 1988). The NRC then requested the ACGIH to consider whether its uranium standard should be revised, and this work is now in progress. In the interim, the NRC is retaining its standard based on 3 μg U per g kidney in the current major revision of 10 CFR Part 20. It is worthy of note that physicians attending an NRC public meeting on this topic pointed out that man can sustain a rather large loss of kidney function, on the order of 75%, without clinical manifestations. Their message was that the reserve function provided by nature can be needed under conditions of kidney disease, and that past uranium exposure could have caused undetected loss of kidney function. For those workers who subsequently suffered from kidney disease unrelated to uranium, this could have adversely affected or prevented recovery. Attending physicians would not likely suspect, or report, uranium involvement (USNRC 1988).

The current NRC inhalation limit for uranium in soluble compounds is 0.2 mg/M^3 of air, averaged over one week, which is approximately equivalent to 8.6 x 10^{-11} μCi/ml for DU, or an intake of about 4 x 10^{-3} μCi/wk. These values are based on an assumed particle size distribution of 1μm AMAD.

2.1.2.3 External Exposure From DU Photons

The estimation of risk from external radiation sources is straightforward. For a given population, the simplest approach is to calculate E, the number of cancer fatalities attributed to the radiation, as the product of:

$$N \text{ persons} \times D \text{ rems} \times C \text{ deaths/person-rem} = E$$

If **D** is the average individual annual dose, **E** is the number of fatalities induced each year. If **D** is the average individual dose accumulated by each person in the exposed population over several years, **E** is the total number of fatalities induced during that period.

When converted for the dose rate effect, the risk coefficients, C, are applicable to large populations receiving 10 rad or more to the red marrow (leukemia) or 40 rad or more to the other radiogenic organs. **C** is obtained as the sum of the risk coefficients for many organs, i.e.,

$$C = \Sigma C_i$$

where i refers to individual organs or tissues. The units of the C_i are deaths per organ-rem. Thus it is evident that **C** is applicable only when each organ or tissue receives approximately the same dose, as with high energy gamma radiation. For example, if the gamma photons do not have sufficient energy to penetrate the compact bone and irradiate the red marrow, C_{marrow} must be removed from the summation to avoid an overestimate of **E**.

If the photons are of very low energy, so that shielding by soft tissue is significant, the dose received by every organ or tissue may be considerably different. In this case the number of deaths caused by the irradiation of organ/tissue i among the exposed population is

$$E_i = N \Sigma C_i d_i$$

and

$$E = \Sigma E_i$$

for the exposed population. (The ICRP used a system of weighing factors W_T in the calculation of its standards, such that:

$$w_{Ti} = C_i/C$$

where the w_{Ti} are, in effect, sensitivity factors, However, since individual organ susceptibilities are reflected in the C_i, rise of the weighing factors is unnecessary when the C_i are used directly.)

For doses of less than 10 rad to the red marrow and 40 rad to the other radiogenic organs the use of the C_i becomes speculative, more so as the doses decrease in magnitude. For exposures that are administered chronically, the single-exposure doses of 10 and 40 rad must be increased. To account for this dose rate effect, radiobiologists currently use correction factors of 2 (female breast cancer) to 10 (general life shortening) (UNSCEAR 1988), i.e., C is divided by a number between 2 and 10 when applied to low dose-rate chronic exposure conditions. Epidemiologists conducting the atomic-bomb survivor study are using a factor of 2.5 (RERF 1988); the NRC is using 3 (Abrahamson 1989). With respect to the collective dose, **ND**, the number of actual fatalities is likely to be zero if **ND** is less than 10,000 person-rem (UNSCEAR 1988).

A few example analyses may be instructive at this point. The following assumptions are used in the <u>first</u> example:

(1) N is 10,000 workers, including only those workers who have received accumulated doses of 25 rad or more to the red marrow.

(2) A 20-year working period is considered.

(3) The radiation is high-energy photons, so that every organ receives approximately the same dose.

(4) The average annual individual dose is 5 rad, so that the average accumulated individual dose for the 20-year period is 100 rem.

Under these conditions the collective dose is 10^6 person-rem. All of the criterion for the statistical significance of C are well met in this case, and

$$E = 10^6 \text{ person-rem} \times 3 \times 10^{-4} \text{ deaths/person-rem} = 300 \text{ deaths}$$

or 3% of the population. While the number of deaths would not likely be 300 exactly, there is little room for optimism that the number would be small, and an effective dose-reduction effort (ALARA) would be obviously indicated.

In the second example only assumption (3) is changed:

(3) The radiation is low-energy photons as emitted by DU.

With this change it is necessary to use individual C_i rather than C because of the nonuniform dose distribution among organs at different depths. DU workers are exposed significantly to photons of 10 different energy levels ranging from 63 to 1001 keV. In the UNSCEAR-1988 report (Table 69, p. 531) risk coefficients are given for 9 organs or tissues, i, and for the "remainder" organs and tissues which are lumped together. These coefficients are the C_i shown in Table B-2 of Appendix B. Each d_i shown in the table is the total dose equivalent to organ i (from all 10 of the photon energy levels mentioned above) per unit dose equivalent delivered to the worker's dosimeter (see Appendix B for methods of calculation.) The units of the d_i are: organ-rem per rem of whole-body dose recorded. All of the d_i are < 1 because of photon attenuation by overlying tissues.

As shown in equation (1), the number of cancer fatalities E_i from the irradiation of each organ or tissue i is the product NC_id_i. The risk, R_i, is the number of deaths per person, or E_i/N, or $C_i\ d_i$. Values of R_i are also given in the table. The sum of the R_i is the total risk from external DU gamma radiation, $R'_{ext} = 2.5 \times 10^{-4}$ cancer fatalities/person-rem. This coefficient is applicable to high doses and dose rates. To correct for the dose rate effect the RERF value of 2.5 is used in the table, providing a DU coefficient of 1×10^{-4}, a factor of 3 lower than the coefficient used for example 1. Thus, E is 100 for example 2. Again, there are few reasons to believe that E would actually be a great deal smaller.

In the third example the assumptions are changed to reflect the external exposures that uranium workers actually receive. Uranium mine workers typically receive about 0.35 rem annually (NCRP 1989). At uranium mills the annual doses vary from 0.2 to 0.4 rem (UNSCEAR-1982). DU workers are estimated to receive an average of about 0.15 rem per year. Thus, in assumption (4) the average annual individual dose is changed from 5 to 0.15 rem and the 20-yr accumulated dose is changed from 100 to 3 rem. It is necessary to abandon the assumption in (1) that each worker has received the statistically significant 25 rem or more. With these changes the collective dose is (10^4 workers x 3 rem) 3 x 10^4 person-rem, which still satisfies the UNSCEAR significance criterion of 1 x 10^4 person-rem. This change in the collective dose reduces E by a factor of 33 (10^6/3 x 10^4) to 3 deaths. Because of the low individual doses (average of 3 rem), statistical significance is lost, so that E should be expressed as 0 to 3 deaths. Since few workers would be expected to remain in DU work for as long as 20 years, 0 might be the most likely outcome among the 10,000 workers.

In the fourth example recognition is made of the fact that no organ doses approach the 40-rad statistically significant dose level established by RERF for solid tumors, and attention is focused on leukemia as caused by irradiation of the red marrow, where doses as low as 10 rad are statistically significant.

From Appendix B, Table B-II, the leukemia fraction of the total risk is ($2.3 \times 10^{-5}/2.5 \times 10^{-4}$) only 0.09. This fraction reduces E from 3 to a number < 1, viz., 0.27. For this number to have meaning, it would be necessary to increase the number of exposed workers from 10,000 to 37,000, to obtain a value for E of either 0 or 1 death. For this example the marrow dose of about 0.7 rem (0.236 x 3) is so small that E = 1 is speculative.

In the fifth example the number of workers significantly exposed to DU photons in the production of projectiles is used rather than the 10,000 number from example (1). This number is about 260 at the 3 plants involved. Thus, the reduction factor for E to use with each example presented above is (260/10,000) 0.026. The results of this reduction are shown below:

Example 1	8 deaths
Example 2	3 deaths

Example 3	0-0.08 deaths (all cancers)
Example 4	0-0.002 deaths (leukemia)

The range of 0-0.002 deaths given for the realistic example indicate that the attribution of even one cancer death from DU gamma radiation exposure to this DU workforce would have to be classified as sheer speculation.

2.2 TUNGSTEN

2.2.1 Processes and Exposure Pathways

2.2.1.1 Manufacture of Kinetic Penetrator Projectiles

One tungsten production site was visited during this study. Manufacturing processes were observed and investigated. Due to the proprietary nature of some of these processes, manufacturing descriptions are not included in this section.

2.2.2 Tungsten: Toxicity And Health Effects

Most of the research investigations on the physiological effect of tungsten followed the commercialization of cobalt-cemented tungsten carbide just before 1940. Thus, most of the investigations concern the toxicity and health effects of cemented tungsten carbide and its constituents, rather than tungsten and its compounds themselves, all of which tend to blur the true toxicity of tungsten to man. The few determinations of toxicity of tungsten and its compounds made before 1950 clearly show a difference between soluble and insoluble tungsten compounds (See Table 2-6); soluble tungsten compounds are distinctly more toxic than insoluble tungsten compounds although toxicity does not completely parallel solubility (Stokinger 1981). The results of these investigations are summarized in Appendix C.

Nickel carbonyl is used to produce the nickel powder utilized in tungsten alloys for kinetic penetrators. Nickel carbonyl is a common industrial compound used in the life cycle of tungsten penetrators; however, it is not present at tungsten penetrator production sites. Metallic nickel combines with carbon monoxide to form nickel carbonyl $Ni[Co]_4$, which decomposes to pure nickel and

TABLE 2-6. PHYSICAL AND CHEMICAL PROPERTIES OF TUNGSTEN AND SOME OF ITS COMPOUNDS

FORMS OF TUNGSTEN	WATER SOLUBILITY
* Tungsten (W)	Insol. hot or cold H_2O
* Tungsten trioxide (native, wolframite) (WO_3)	Insol. hot or cold H_2O
* Tungstic acid (ortho) (H_2WO_4) hot H_2O	Insol. cold H_2O, sl. sol.
* Sodium tungstate (Na_2WO_4 $2H_2O$)	410 g/liter (0°C), 825 g/liter (20°C), 1235 g/liter (100°C)
Tungsten carbide (WC)	Insol. cold H_2O
Tungsten diboride (WB_2)	Insol. hot or cold H_2O
Tungsten hexachloride (WCl_6)	Decomposes 60°C H_2O
Tungsten oxytetrachloride ($WOCl_4$)	Decomposes hot or cold H_2O
Tungsten hexafluoride (WF_6)	Decomposes hot or cold H_2O
Tungsten disulfide (native, tungstenite) (WS_2)	Insol. cold H_2O
Phosphotungstic acid ($H_3[P(W_3O_{10})_4]$ $24H_2O$)	Sol. cold H_2O
Ammonium paratungstate $[(NH_4)_6W_7O_{24}$ $6H_2O]$	28 g/liter (15°C)

A more complete listing of physical and chemical properties of selected tungsten compounds can be found in DHEW (NIOSH) Publication No. 77-127 (Criteria for a recommended standard-occupational exposure to tungsten and its compounds), Washington, DC 977, pp. 166-170.

* Commonly used in tungsten penetrator production

carbon monoxide on heating to 200°C (Mond process). This reaction provides a convenient and efficient method for the refinement of nickel.

Nickel carbonyl is a liquid with a high vapor pressure at room temperature. Exposure to vaporized nickel carbonyl outside of the nickel refining industry occurs in electroplating operations and the electronics industry. The highly insoluble vapor penetrates to the alveoli with resultant edema (2-day latent period). Nickel metal has been detected within alveolar cells following exposure to nickel carbonyl; this suggests that nickel carbonyl penetrates the cells and decomposes there to nickel metal.

Nickel carbonyl is both carcinogenic and extremely toxic. Illness due to nickel carbonyl exposure begins with headache, nausea, vomiting, and epigastric or chest pain followed by cough, hyperpnea, cyanosis, gastrointestinal distress, and weakness. These symptoms may be accompanied by fever and leukocytosis. The more severe cases of nickel carbonyl exposure progress to pneumonia, respiratory failure, and eventually cerebral edema and death. Autopsy studies of nickel carbonyl victims show the largest concentrations of nickel to be in the lungs with lesser amounts in kidney, liver, and brains. Blood nickel levels immediately following exposure to nickel carbonyl provide guidelines as to the severity of exposure and indication for chelation therapy.

2.2.2.1 Occupational Exposure And Toxicology

Effects of both short-term and long-term occupational exposures to tungsten and its compounds have been identified among employees in the cemented tungsten carbide industry. The only work areas in this industry that permit specific evaluation of the effects of tungsten and its compounds are those processing stages that precede the incorporation of other toxic metals into the final products. Only two human studies meeting this criterion have been documented (Kaplun and Mezentseva 1959, Mezentseva 1967). These studies showed that the effects of inhaled tungsten and tungsten compounds are exerted chiefly on the respiratory system. Radiologic signs of pulmonary fibrosis were reported by Mezentseva (1967) and by Kaplun and Mezentseva (1959) in 9-11% of the hard-metal workers who were exposed to dusts of tungsten and its compounds.

Most reports of occupational exposure to tungsten and its compounds, with the exception of the two studies already mentioned, deal with the effects of mixed dusts containing cobalt. The effects of such mixed dusts were chiefly respiratory in nature, although some dermal effects were evident. The pulmonary involvement reported in a number of these studies was characterized by exertional dyspnea, coughing, and weight loss (Fairhall et al. 1947, Dorsit et al. 1970, Bech 1974, Bech et al. 1962). These clinical signs sometimes progressed to extrinsic asthma (Bruckner 1967), diffuse interstitial pneumonitis (Coates and Watson 1971), or fibrosis (Dorsit et al. 1970, Baudouin et al. 1975, Rochemaure et al. 1972). The type of pneumoconiosis seen in the cemented tungsten carbide industry is referred to as "hard-metal disease." While the total dust levels and cobalt concentrations were reported in most studies, tungsten concentrations were documented in only few cases. Most dust particles generated in various operations in which tungsten is processed and used are less then 5 μm in diameter and hence are in the respirable size range (Dorsit et al. 1970, Bech et al. 1962, Meztenseva 1967, Lauring and Wergeland 1970, Reber 1969).

Some authors described the pulmonary responses of cemented tungsten carbide workers as hypersensitivity (Dorsit et al. 1970, Baudouin et al. 1975). This response was so described because of the reversibility of some clinical symptoms, the occasional radiologic improvement on withdrawal from exposure, and the recurrence of symptoms on exposure. Bruckner (1967) diagnosed extrinsic asthma in a cemented tungsten carbide worker and attributed it to a hypersensitivity mechanism. This worker experienced asthmatic symptoms 1-3 minutes after beginning work, even though he wore a respirator designed to remove particles of 0.6 μm diameter or larger.

Two studies (Schwartz et al. 1945, Skog 1963) described the dermatologic effects of occupational exposures to unspecified levels of dusts in cemented tungsten carbide industries. Schwartz et al. (1945) stated that 20 workers employed 1 month or more in this industry developed erythematous, papular dermatitis, mainly on the sides of the neck, the eyelids, and the forearms. While the abrasiveness of the dust reportedly contributed to the sensitization process, cobalt sensitization was concluded to be the cause of the dermatitis. Skog (1963) reported skin effects including contact eczema, pruritus,

folliculitis, and neurodermatitis, in 34 (9.4%) of the 361 workers in the cemented tungsten carbide industry. Cobalt sensitization was detected by patch tests in 3 of the 14 workers with contact eczema, found mainly on the eyelids and between the fingers. Skog (1963) concluded that the primary irritant effect of the combined metal dusts produced the contact eczema.

Although these studies are well documented in terms of the observed effects, it is difficult to distinguish the effects of tungsten and its compounds from those produced by cobalt and perhaps other metals and compounds. Most of the authors attributed the effects of these mixed exposures primarily to the presence of cobalt.

2.2.2.2 Tungsten Occupational Exposure Limits

The current U.S. Occupational Safety and Health Administration (OSHA) exposure limits for insoluble and soluble tungsten are 5 mg/M^3 and 1 mg/M^3, respectively. The corresponding OSHA occupational limits for cobalt and nickel, with which tungsten may be alloyed, are 0.05 mg/M^3, and 1 mg/M^3 (insoluble) and 0.1 mg/M^3 (soluble), respectively. Current ACGIH TLV values for nickel are 0.05 mg/M^3 for both soluble and insoluble forms.

3.0 QUALITATIVE COMPARISON OF THE RISKS FROM KINETIC ENERGY PENETRATOR MANUFACTURING, TESTING, RECYCLING, AND DECOMMISSIONING FOR DEPLETED URANIUM VERSUS TUNGSTEN ALLOYS

Any comparison of risk must evaluate both the exposure to DU or tungsten, and the consequences of that exposure. This comparison attempts to contrast the qualitative differences in exposure and consequences.

3.1 PROPERTIES OF DU AND W AFFECTING EXPOSURE

The physical, chemical and biological properties of DU and its oxides compared with W that affect the nature, magnitude or duration of occupational, military, or environmental exposures must be considered. These properties were summarized in Section 1.1. These properties govern the fragmentation of the metal alloys under mechanical forces arising from machining or kinetic energy penetrator impacts; the chemical reactivity of the fragments so generated in various media; and the transport, fate and bioavailability of DU and W in the occupational, military and ambient environments.

3.2 OVERVIEW

The degree of internal chemical health risk associated with a unit concentration of suspended particles in any environment is a function of the fraction of the suspended particles that can be deeply respired into and retained in the lungs, and the fraction of those deeply respirable particles that contain soluble metal and oxides. The solubilities of the metals and their oxides as a function of pH, pE, counter ion and ligand concentrations in biological fluids will determine the biological availability of the metal when exposure occurs via inhalation, ingestion or dermal contact.

The efficiency with which suspended particles are deeply respired and trapped in the lungs increases dramatically for particles of less than 10 microns diameter. Due to its pyrophoric nature, the tendency of DU to form DU oxide particles with a greater proportion of particles of less than 10 micron diameter than for W, increases the inhalation exposure per unit suspended particle concentration of DU relative to W.

Although DU is virtually insoluble and DU oxides are only marginally soluble in lung fluids, both DU and DU oxides are more soluble than W and W oxides. Thus, for a given unit of exposure to deeply respirable particles, a greater proportion of DU will be in the soluble form, decreasing the dose rate delivered during occupational exposure.

The insoluble forms of DU and W both represent health hazards when retained in the lung, due to the irritant nature of insoluble solids. In DU the insoluble form also represents an internal radiation hazard.

With respect to the external radiation hazards of DU and its short-lived daughters, the intensities of alpha and beta particle fluxes and gamma radiation fluxes are a function of distance from the DU. There is no corresponding external radiation exposure hazard associated with W.

3.3 OCCUPATIONAL ENVIRONMENT

The most significant physical difference in alloys is that DU has the lower hardness and tensile strength, suggesting that the mechanical energy required to machine W is greater, further suggesting that the size of the particles formed during machining will generally be smaller.

The most significant chemical difference between DU and W is the pyrophoric nature of DU. When small particles are formed, they will spontaneously burst into flame under ambient air temperatures and partial pressures of oxygen gas. Larger particles will ignite if heated, as is the case during machining of DU alloys or as a result of kinetic penetrator fragmentation following impact. Morphological studies of DU oxide particles generated in kinetic penetrator testing indicate that the particles are primarily insoluble DU oxides and that the particles readily crumble into smaller pieces under even weak mechanical forces (Patrick and Cornette 1978). The formation of such DU oxide particle structure is a function of the high temperatures associated with kinetic penetrator impact on "hard" targets and may not necessarily reflect the structure of DU oxide particles formed during milling operations, however.

Based on the greater hardness and tensile strength of W compared to DU, machining of W should result in a particle size distribution function (PDF) that favors finer particles relative to DU. However, based on the pyrophoric nature of DU, the initial particle size PDF generated in milling is modified by spontaneous ignition of the smaller particles, shifting the DU particle size PDF first to larger particles, because DU oxides are less dense than DU, and then to favor finer particles, due to mechanical fragmentation of the DU oxide crust. Whether the DU or W particle size PDFs include the greater proportion of deeply respirable particles cannot be ascertained at present based on the data received.

The potentially most significant route of non-radiation exposure in the occupational environment to DU and W is inhalation. The most exposed individual (MEI) to metal vapor is probably involved in the casting of metal into ingot molds, although individuals involved in the UF_4 reduction process, and to a lesser extent the roasting process, may also be exposed to elevated levels, as well. The MEI for suspended particles of the metal and its oxides is probably the operator of the machine tools used to shape the ingots, but individuals involved in waste management and housekeeping activities may also experience potentially substantial exposures.

Due to the institution of ALARA practices in the manufacture, storage, transport, use and disposal of DU, ocupational exposures tend to average about 10% of the current DU allowable limits, while those for W are likely to average 20% to 50% of the limits, based on average performance in other metallurgical industries. On the other hand, based on the allowable occupational exposure limits for DU and W, DU is considered to be between 25 and 20 times more toxic per unit exposure than W for the insoluble and soluble forms, respectively.

To the greater chemical toxicity risks of DU exposure must then be added those attributable to radiation exposures; and here, of course, DU dominates, since W is not radioactive. Thus, while ALARA practices will tend to reduce average occupational, military and environmental exposures to a fraction of the allowable limits, perhaps as low as 5 to 10 percent of the limit, radiation risks will remain. Estimates of lifetime increased cancer risk associated with

exposure to DU radiation in the occupational environment were displayed in Table 1-5.

3.4 MILITARY ENVIRONMENT

During kinetic penetrator testing, DU tends to fragment into smaller particles than W initially, and that particle size PDF is further reworked as a result of fine particle ignition to favor even finer particles. Subsequent weathering under ambient conditions of sunlight, precipitation and temperature, combined with the mechanical disturbance of the soil during lawn maintenance activities, will act to further reduce the particle size distribution.

Precautions taken during the testing of armor-piercing ordnance, post-testing cleanup and area maintenance and housekeeping minimize exposure of military personnel to airborne DU and DU-related external radiation. Whether such precautions are or would also be taken for W is not clear. Under non-combat conditions, the MEIs are probably the military personnel situated closest to the ammunition racks in tanks and helicopters, although the loading and unloading of storage lockers, magazines and ammunition racks could also represent sources of exposures. Under combat conditions, the MEIs are probably the ground troops that re-enter a battlefield following the exchange of armor-piercing munitions, either on foot or on motorized transports. The health risks associated with internal and external DU exposure during combat conditions are certainly far less than other combat-related risks.

Following combat, however, the condition of the battlefield, and the long-term health risks to natives and combat veterans may become issues in the acceptability of the continued use of DU kinetic penetrators for military applications.

3.5 AMBIENT ENVIRONMENT/PUBLIC EXPOSURE

In the ambient soil environment, the pH, pE, counter ion and ligand concentrations will determine the solubilities of the metals and their oxides as a function of the initial oxidation state of the metal. Once solubilized, the mobilities of the metal ions will be determined by valence charge, ion size, the

cation exchange capacity of the substrate, counter ions and ligand concentrations, all affecting metal ion adsorption to substrate, and the fraction of substrate void volume containing pore water, their diffusion coefficients, and specific gravities. As pH, pE, ligand and counter ion concentrations will change with depth and distance from the point of origin, these changes must also be factored into an analysis of the mobility of the metal ions.

The absolute mobilities of the metal ions will be determined by the exchangeable cation concentrations in and rate of flow of precipitation water through the vadose zone and the exchangeable cation concentrations and rate of flow of groundwater in the saturated zone. The threat to groundwater or surface water is thus determined by the mobilities of the metal cations in the substrate under the pH, pE, counter ion and ligand concentration conditions encountered; the flow rates of precipitation and groundwater; and the depth to groundwater or distance to surface water.

Based on the half-life of U-238, given sufficient time DU will reach underlying groundwater and nearby surface waters. The soil loading rate, the leachate generation rate, the leachate dispersion rate in surface and subsurface substrates and in surface waters, the distances to ground and surface waters, and the ground and surface water flows will determine the concentrations in groundwater and surface water plumes.

Metal ions can also reach nearby surface waters via precipitation runoff in the soluble or insoluble forms. Soluble forms move with the overland water flow, while insoluble forms move with particles of either alloy or soil origin transported by shear forces arising from laminar and turbulent flows over the contaminated particle surfaces. The relative distribution between the fraction transported as soluble material and that transported associated with particles is determined in part by the intrinsic solubility of the various species under the conditions encountered, in part by the affinity of the metal cations for particle surfaces, and in part by the rates of adsorption and desorption relative to the rate of flow of the water.

Once present in the surface water environment, the dense metal or metal oxide particles will rapidly sink to the sediments, along with metal cations associated with settleable solids. Solubilized metal ions with a strong affinity for sediment particles will also accumulate there. The subsequent donwstream transport of the contaminant will be determined primarily by the shear forces acting on the sediment particles. Where the metal cations have a disproportionate affinity for fine particles of soil or sediment origin, the downstream transport will be enhanced.

Neither W or U are readily bioaccumulated by aquatic or terrestrial plant or animal life, although U is somewhat more bioaccumulative than W. (Erickson et al. 1989).

A detailed analysis of the transport and fate of U and W as a function of ambient conditions by medium is beyond the scope of this evaluation.

The potentially most significant environmental exposures via the inhalation route probably occur during metal manufacture, where residential neighborhoods may be adjacent to facility boundaries, whereas in open air testing the secluded nature of military test ranges is likely to preclude significant public exposure by this pathway.

During manufacture, particulates are removed from the air by HEPA filters (Section 2.1.1) and little exposure should occur to the public. However, raw materials and waste storage and waste disposal activities in the past may have resulted in contamination which could lead to contamination of water supplies and potential risk to users of those water supplies if the water is used without first being treated. Nevertheless, such impacts are outside the scope of this assessment.

4.0 BIBLIOGRAPHY

Aamodt, R.L. (1973). Retention and Excretion of Injected ^{181}W Labeled Sodium Tungstate by Beagles. Health Physics 24: 519-524.

Aamodt, R.L. (1975). Inhalation of ^{181}W Labeled Tungstic Oxide by Six Beagle Dogs. Health Physics 28: 733-742.

Abrahamson, S., et al. (1989). Health Effects Models for Nuclear Power Plant Accident Consequence Analysis; Part II: Scientific Basis for Health Effects Models. NUREG/CR-4214. Washington DC: U.S. Government Printing Office.

Anderson, J.E. and Ad Hoc Working Group for Depleted Uranium (1974). Medical and Environmental Evaluation of Depleted Uranium. Army Materiel Command.

Bachelor, L. D. (1988). Colonel, GS Chief of Staff. U.S. Army Armament, Munitions, and Chemical Command, Rock Island, IL Memo to Commander, Lake City Army Ammunition Plant, August 8, 1988

Ballou, J.E. (1960). Metabolism of ^{181}W in the Rat. U.S.A.E.C. Document HW-64112, U.S.A.E.C. Document HW-64112, U.S.A.E.C., Oak Ridge, Tennessee.

Battelle 1987. Battelle, Pacific Northwest Laboratory, Radiological Hazards Associated with Depleted Uranium Munitions, U.S. Army Belvoir RD&E Center. November 16-20, 1987.

Baudouin, J.; Jobard, P.; Moline, J.; Labandier, M.; Roullier, A.; and Homasson, J.P. (1975). (Diffuse Interstitial Pulmonary Fibrosis--Responsibility of Hard Metals.) Nouv Presse Med 4: 1353-55. (Fre) as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Bech, A.O.; Kiplin, M.D.; and Heather, J.C. (1962). Hard Metal Disease. Br. J. Ind. Med. 19: 239-52 as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Bech, A.O. (1974). Hard Metal Disease and Tool Room Grinding. J. Soc. Occup. Med. 24: 11-16 as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C.

Becker, N.M.; Vanta, E.B.; and Crews, R.C. (1989). Environmental Monitoring for Depleted Uranium at Eglin Air Force Base Test Areas C-64, C-64C, and C-74L 1974-1988.

Bernhardt, D.E.; Nielson, K.K.; and Grant, M.W. (1984). Risk Assessment for Transportation and Disposal of DU Oxide.

Bernhardt, D.E.; Owen, D.H.; and Rogers, V.C. (1988). Facility Closure Report, Depleted Uranium Manufacturing Facility.

Boldt, R.E. (1988). Acting Chief, Radiological and Inorganic Chemistry Division, U.S. Army Environmental Hygiene Agency, Aberdeen Proving Ground, MD. Memo to Commander, U.S. Army Armament, Munitions and Chemical Command, Rock Island, IL, September 1, 1988.

Bruckner, H.C. (1967). Extrinsic Asthma in Tungsten Carbide Worker. J. Occup. Med. 9: 518-19 as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Butterworth, A. (1959). Human Data on Uranium Exposure. HASL-58; 1959. Cristy, M.; Eckerman, K. F. Specific Absorbed Fractions of Energy at Various Ages from Internal Photon Sources. I. Methods. ORNL/TM-8381/V1.

Cardin, C.J. and Mason, J. (1975). Molybdate and Tungstate Transfer by Rat Ileum. Competitive Inhibition by Sulfate. Biochem. et Biophys. Acta 455: 937-946.

CH2M Hill. (1985). (Superfund) Feasibility Study for Fields Brook, Ashtabula, Ohio, for the U.S. Environmental Protection Agency Region V, Chicago, IL.

Chambers, D.R., Markland, R.A.; Clary, M.K.; and Bowman, R.L. (1982) Aerosolization Characteristics of Hard impact Testing of Depleted Uranium Penetrators. U.S. Army Armament Research and Development Command Report No. ARBRL-TR-02435.

Coates, E.O. and Watson, J.H.L. (1971). Diffuse Interstitial Lung Disease In Tungsten Carbide Workers. Ann. Intern. Mde. 75: 709-16 as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Cohen, H.J.; Johnson, J.L.; and Rajagopalan, K.V. (1974). *Arch. Biochem Biophys 164: 440-446.

Cole, L.W. (1989). Health Assessment of Field Use of DU in Chemical Energy Warheads.

Cytron, S.J. (1989). U.S. Army Radioactive Waste Disposal Support Plan (Draft). Prepared for U.S. Army Armament Research, Development, and Engineering Center. Report ARAED-TR-89001.

Delahant, A.B. (1955). An Experimental Study of the Effects of Rare Metals on Animal Lungs. Arch. Ind. Health 12: 140-146.

DHEW (NIOSH) Publication No. 77-127. (1977). Criteria for a Recommend Standard...Occupational Exposure to Tungsten and Its Compounds, Washington, D.C., September 1977.

Dolan, L.C.; Herman, D.L.; Kennedy, J.D., et al. Plan for the Production of 2.1 Percent Uranium Metal at the Feed Material Production Center. Prepared for Westinghouse Materials Company of Ohio. Contract No. 1183.

Dorsit, G.; Girard, R.; Rousset, H.; Brune, J.; Wiesendanger, T.; Tolot, F.; Bourret, J.; and Galy, P. (1970). Pulmonary Fibrosis in Three Individuals Working in the Same Factory and Exposed to Cobalt and Tungsten Carbide Dusts -- Pulmonary Problems in the Hard Metal Industry. Sem Hop 46: 3363-76, (Fre) as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977)

DUDOSE: Computer Codes for Calculating Dose Resulting from Accidents Involving Munitions Containing Depleted Uranium. Battelle Pacific Northwest Lab, 1986.

Ebinger, M.H.; Essington, E.H.; Gladney, E.G.; Newman, B.D.; and Reynolds, C.J. (1989). Preliminary Report on the Long Term Fate of DU at Aberdeen and Yuma Proving Grounds. Los Alamos National Laboratory.

Elder, J.C.; Tillery, M.I.; and Ettinger, H.J. (1976). Hazard Classification Test of GAU-8 Ammunition by Bonfire Cookoff With Limited Air Sampling. Los Alamos National Laboratory, New Mexico. Report No. LA-6210-MS.

Elder, J.C., and Tinkle, M.C. (1980). Oxidation of Depleted Uranium Penetrators and Aerosol Dispersal at High Temperatures, Los Alamos National Laboratory, New Mexico. Report No. AL-8610-MS.

Environmental Radiation Monitoring (1987). U.S. Army Combat Systems Test Activity Aberdeen Proving Ground. Publication No. 385-328.

Erikson, R.L., Hostetler, C.J.; Divine, J.R.; and Price, K.R. (1989) Environmental Behavior of Uranium Derived from Depleted Uranium Alloy Penetrators. Prepared for U.S. Army Combat Systems Test Activity. Aberdeen Proving Ground. Contract No. DE-AC06-76RLO1830.

Eve, I. S. (1964). Some Suggested Maximum Permissible Single Intakes of Uranium. Health Physics. 10:No.11.

Fairhall, L.T.; Castberg, H.T.; Carrozze, N.J.; and Brinton, H.P. (1947). Industrial Hygiene Aspects of the Cemented Tungsten Carbide Industry. Occup Med 4: 371 as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Fairhall, L.T.; Keenan, R.G.; and Brenton, H.P. (1949). Cobalt and the Dust Environment of Cemented Tungsten Carbide Industry. Public Health Rep 64: 485-490.

Fleishman, D.; Krotz, S.; and Jilva, A. (1966). The Metabolism of Elements of High Atomic Number. U.S.A.E.C. Document UCRL-14739, 2, 69-86. U.S.A.E.C., Oak Ridge, Tennessee.

Goldman, E.I.; Mezentseva, N.V.; and Mogilerskaya, O.Y. (1967). Industrial Dust of Luminiophores, in Toxicology of the Rare Metals; Izraelson, Z.I. (ed), U.S. Dept of Commerce, 1967, pp 170-181 as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Gordon, J. (1988). Analysis and Assessment of SEAD Capability for Processing Depleted Uranium Contaminated Manufacturing Equipment. Prepared for U.S. Army Industrial Engineering Activity. Contract No. DAAAD8-86-D-0205.

Gordon, J. (1988). Review and Analysis of Disposition Alternatives for Depleted Uranium Contaminated Manufacturing Equipment. Prepared for U.S. Army Industrial Engineering Activity. Contract No. DAAA08-86-D-0205.

Harris, H.G. (1988). Application for Material License test Areas (TA) C-64 and (TA) C-80. Eglin AFB, FL. To NRC From Armament Division, Eglin AFB, FL.

Health Physics and Radiological Health Handbook. (1984). Nucleon Lectern Associates. Olney MD.(1978).

Hodge, H. C.; Stannard, J. N.; Hursh, J. B.; editors. (1973). Uranium-Plutonium- Transplutonium Elements. New York: Springler-Verlag.

Hursh, J. B., et al. (1969). Oral Ingestion of Uranium by Man. Health Physics. 17:No.4.

ICRP (1959). International Commission on Radiological Protection. Report of Committee II on Permissible Dose for Internal Radiation. Health Physics. Vol. 3. 1960 (reprinted from ICRP 1959).

ICRP (1968). International Commission on Radiological Protection. Report of the Task Group on Reference Man. Pergamon Press, NY.

ICRP (1977). International Commission on Radiological Protection. Recommendations of the ICRP. ICRP Publication 26. Oxford: Pergamon Press.

ICRP (1978). International Commission on Radiological Protection/Committee 2. Limits for Intakes of Radionuclides by Workers. ICRP Publication 30. Oxford: Pergamon Press.

ICRP (1979). Limits for Intakes of Radionuclides by Workers. ICRP Publication No. 30, Part 1-4.

ICRP (1981). International Commission on Radiological Protection. Report of the Task Group on Reference Man. Pergamon Press, NY.

Johnson, J.L.; Rajagopalan, K.V.; and Cohen, H.J. (1974). Molecular Basis of the Biological Function of Molybdenum--Effect of Tungsten of Xanthine Oxidase From Sulfite Oxidase in the Rat. J. Biol. Chem. 249: 856-866.

Johnson, J.L.; Wand, W.R.; Cohen, H.J.; Rajagopalan, K.V. (1974). Molecular Basis of the Biological Function of Molybdenum -- Molybdenum-Free Xanthine Oxidase from the Livers of Tungsten-Treated Rats.

Kaplun, Z.S.; and Menzentaseva, N.V. (1959). Hygienic Evaluation of Aerosols Formed in the Manufacture of Hard Alloys. Gig Sanit 24: 16-22, (rus) as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Karantassis, T. (1924). On the Toxicity of Compounds of Tungsten and Molybdenum. Ann. Med. Leg 5: 44-50 as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Kaye, S.V. (1968). Distribution and Retention of Orally Administered Radiotungsten in the Rat. Health Physics 15: 399-417.

Kinard, F.W.; and Van de Erve, J. (1941). The Toxicity of Orally Ingested Tungsten Compounds in the Rat. J. Phamacal Exp. Ther. 72: 196-201.

Kirk, W.S. Depleted Uranium. Kirkland, C.G. (1986). Letter of Need, Department of The Air Force.

Luo, X.M.; Wei, J.J.; and Yang, S.P. (1983). Inhibitory Effect of Molybdenum on Esphageal and Forestomach Carcinogenesis in Rats. J. National Cancer Institution 71: 75-80.

Ludwig, G. (1985). Particle Size Distribution and Relative Uranium Contents of Airborne Dusts in a Depleted Uranium Facility.

Luessenhop, A. J., et al. (1958). The Toxicity in Man of Hexavalent Uranium Following Intravenous Administration. American Journal of Roentgenology; Jan 1958.

Magness, C. Reed (1985). Environmental Overview for Depleted Uranium. Chemical Research & Development Center. U.S. Army Armament, Munitions & Chemical Command, Aberdeen Proving Ground, MD. CRDC-TR-85030.

Mezentseva, N.V. (1967). Tungsten in Toxicology of the Rare Metals. Izrael'son Z.I. (ed): Springfield, VA. U.S. Dept of Commerce, National Technical Information Service, pp 28-35 (NTIS ACE-tr 6710) as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Miller, C.W.; Davis, M.V.; Goldman, A.; and Wyatt, J.P. (1953). Pneumonoconiosis in the Tungsten Carbide Tool Industry. AMA Arch. Ind. Hyg. Occup. Med. 8: 453-464 as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Morrow, P. E., et al. (1982). Metabolic Fate and Evaluation of Injury in Rats and Dogs Following Exposure to the Hydrolysis Products of Uranium Hexafluoride. NUREG/CR-2268. Washington DC: U.S. Government Printing Office.

Muller, A.B.; and L.E. Duda. (1985). The Uranium-Water System: Behavior of Dominant Aqueous and Solid Compounds; SAND 83-0105, Albuquerque; Sandia National Labs; p. 160.

Nadeenko, V.G. (1966). Maximum Permissible Concentrations of Tungsten in Water. Hyg. Sanitary 31: 197-203 as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

National Academy of Science, (1977). Drinking Water and Health, NRC Press, Washington, DC.

National Academy of Sciences - National Research Council/Committee on the Biological Effects of Ionizing Radiation (BEIR IV Committee). (1988). Health Effects of Radon and Other Internally Deposited Alpha-Emitters. Washington DC: National Academy Press.

National Academy of Sciences - National Research Council/Committee on the Biological Effects of Ionizing Radiation (BEIR V Committee). 1990. Health Effects of Exposure to Low Levels of Ionizing Radiation. Washington, D.C.: National Academy Press.

NCRP (1975). National Council on Radiation Protection and Measurements. Alpha-Emitting Particles in the Lung. NCRP Report No. 46. Bethesda,MD.

NCRP (1980). National Council on Radiation Protection and Measurements. Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations. NCRP Report No. 64. Bethesda,MD.

NCRP (1989). National Council on Radiation Protection and Measurements. Exposure of the U.S. Population from Occupational Radiation. NCRP Report No. 101. Bethesda,MD.

National Institute for Occupational Safety and Health/Center for Disease Control/U.S. Department of Health and Human Services. (1982). Interim Report No. 1, TA 82-050 (on uranium exposures at TNS, Inc., Jonesboro, TN). NIOSH.

NSMC. 1988. National Systems Management Corporation, Arlington, VA, Technical Report; Review and Analysis of Dispostion Alternatives For Depleted Uranium Contaminated Manufacturing Equipment, Prepared for U.S. Army Industrial Engineering Activity AMXIB, Rock Island, IL, October 19, 1988.

Nelson, I.C. and Price, K.R. (1989). Review of Environmental Radiation Monitoring for the Depleted Uranium Test Areas. Contract No. DE-AC06-76RLO1830. Battelle Memorial Institute, TD-2761.

Patrick M.A. and Cornette, J.C. (1978). Morphological Characteristics of Particulate Material Formed from High Velocity Impact of Depleted Uranium Projectiles with Armor Targets. Air Force Armament Laboratory, Publication No. AFATL-TR78-117.

Pierre Committee (1978). Use of Depleted Uranium Munitions (Hazard Evaluation). U.S. Army Armament Research and Development Command.

Radiation Effects Research Foundation (RERF). (1988). Preston, D. L.; Pierce, D. A. The Effect of Changes in Dosimetry on Cancer Mortality Risk Estimated in the Atomic Bomb Survivors. Rad. Res. 114.

Reber, E. (1969). Investigations on Dust Hazards Accompanying the Production and Machining of Hard Metals. Staub-Reinhalt Luft 29:57-62, (Ger) as cited in DHEW (NIOSH) Publication No. 77-127, Washington, DC. (1977).

Rochemaure, J., Anola, M., Triquest, G., and Meyer, A. (1972). A Case of Pulmonary Fibrosis--Possible Role of Exposure to Tungsten Dust. J. Fr. Med. Chir. Thoac 26: 305-12, (Fre) as cited in DHEW (NIOSH) Publication No. 77-127, Washington, DC (1977).

Scherpers, G.W.H. (1971). Lung Tumors of Primates and Rodents. Ind. Med. 40: 48-53 as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Schwartz, L.; Peck, S.M.; Blair, K.E.; and Markuson, K.E. (1945). Allergic Dermatitis Due to Metallic Cobalt. J Allergy 16: 51-53 as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Sittig, M. Handbook of Toxic and Hazardous Chemicals and Carcinogens, 2nd Edition, Noyes Publications, New Jersey.

Skog, E. (1963). Skin Affecting Caused by Hard Metal Dust. Ind. Med. Surg. 32: 266-68, as cited in DHEW (NIOSH) Publication No. 77-127, Washington, D.C. (1977).

Smith, L.E. (1988). Chief Safety Office, Department of the Army, Letter to the Nuclear Regulatory Commission Region III, Glen Ellyn, IL, October 6, 1988.

Spoor, N. L. (1968). Occupational Hygiene Standards for Natural Uranium. AHSB (RP) R77.

Stafford, P.T. (1985). Tungsten - Mineral Facts and Problems. Bureau of Mines Bulletin No. 675.

Stokinger, H.E. (1981). The Metals; Tungsten in Patty's Industrial Hygiene and Toxicology. Third Edition, Clayton, G.D. and Clayton, F.E> (eds). John Wiley and Sons, New York, pp. 1981-1994.

UNSCEAR (1982). United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR Committee). Sources, Effects and Risks of Ionizing Radiation, 1982 Report to the General Assembly. New York.

UNSCEAR (1988). United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR Committee). Sources, Effects and Risks of Ionizing Radiation, 1988 Report to the General Assembly. New York.

USAF. (1978). Air Force Armament Laboratory. Morphological Characteristics of Particulate Material Formed from High Velocity Impact of Depleted Uranium Projectiles with Armor Targets. AFATL-TR-78-117. November 1978.

U.S. Code of Federal Regulations, Title 10, Part 20. (1989). Nuclear Regulatory Commission. Washington DC: Federal Register.

USDOI. (1985). United States Department of the Interior. Mineral Facts and Problems, 1985 Edition. Bureau of Mines, Bulletin 675.

USEPA 1989. United States Environmental Protection Agency. Health Effects Assessment Summary Tables. Second Quarter, 1989. OERR 9200.6-303-(89-2). Office of Research and Development, Washington, DC, April.

U.S. Nuclear Regulatory Commission. (1976). Denial of Petition for Rulemaking, National Resources Defense Council, Docket No. PRM-20-5. Washington DC: Federal Register, Vol. 41, No. 71, 15371-15379.

U.S. Nuclear Regulatory Commission. (1988). Proceedings of Meeting on Ultrasensitive Techniques for Measurements of Uranium in Biological Samples; Nephrotoxicity of Uranium. NUREG/CP-0093. Washington DC: U.S. Government Printing Office.

U.S. Nuclear Regulatory Commission. (1989). Proposed Commission Policy Statement on Exemptions from Regulatory Control. SECY-89-184 (reissued). Washington DC: NRC Public Document Room.

Vengerskaya, K.Y.; and Salikhodzhaev, S.S. (1962). Some Problems Relating to the Effects of Tungsten Power on Humans.Gig. Tr. Prof. Zabol. 6: 27-29, (Rus.) as cited in DHEW (NIOSH), Publication No. 77-127, Washington, D.C. (1977).

Voegtlin, C.; Hodge, H. C.; editors (1953). Pharmacology and Toxicology of Uranium Compounds. New York: McGraw-Hill.

Walz, M.J. (1982). Depleted Uranium Test Range Fragment Reclamation. Air Force Armament Laboratory. Document No. AFATL-TR82-49.

Wei, H.J.; Duo, X.M.; and Yang, S.P. (1985). Effects of Molybdenum and Tungsten on Mannary Carcinogenesis in Sprague-Dawley Rats.J. National Cancer Institution 74: 469-473.

Weigel F. (1980). Chapter 5: Uranium in Chemistry of the Actinide Elements (2nd ed.); J.J. Katz, G.T. Seaborg, and L.R. Morss eds, New York; Chapman and Hall; p. 169-442.

Whittaker, M. Corporate Health Physicist, Chem-Nuclear Systems, Inc., Columbia, SC via Hayes J.L., Supervisor, DOD Programs, (1987). Letter to Mr. Cardenuto, U.S. Army AMCCOM, Rock Island, IL, June 3, 1987.

Wilsey, E.F. and Bloore, E.W. M774 Cartridges Impacting Armor-Bustle Targets: Depleted Uranium Airborne and Fallout Material. U.S. Army Ballistic Research Laboratory Report No. BRL-MR-3760.

Wing, J. F., et al. (1965). Accidental Acute Inhalation Exposure of Humans to Soluble Uranium. NLCO-951.

Appendix A

Cancer Mortality Risk Coefficient Update

APPENDIX A

CANCER MORTALITY RISK COEFFICIENT UPDATE

In the Section 2.1.2.1 risk analysis the overall ICRP-26 cancer fatality risk coefficient of 1.25×10^{-4} per personrem, and the component coefficients for specific organs, were used. The primary source of data for these coefficients was (and continues to be) the epidemiology study of the atomic bomb survivors. It has since been determined that radiation-induced excess cancer deaths inferred from this study must be attributed to somewhat lower doses (UNSCEAR). An important effect of this finding has been the necessity of re-examining the risk coefficients. Since the coefficients were derived from single-exposure data, whereas most government standards are applicable to chronically administered annual exposures, the resulting re-examinations have included consideration of dose rate effect. The dosimetry corrections tend to increase the coefficients, while dose rate effect corrections tend to decrease them.

In the UNSCEAR 1988 report a range is given, 0.4 to 4×10^{-4} cancer deaths per personrem for adults; the EPA is now using the 4×10^{-4} value in its risk assessments, even for populations that include children. A recent report issued by the Radiation Effects Research Foundation (RERF, formerly the Atomic Bomb Casualty Commission) indicates a preference for 3×10^{-4} for adults, including a correction factor of 2.5 for the dose rate effect (RERF 1988). Based on an exhaustive study by a large group of national experts assembled by the NRC, that agency is using 5×10^{-4} in its development of a Below Regulatory Concern policy (USNRC 1989). The study was actually performed as part of the new reactor safety study, which found 2×10^{-4} to be a central value applicable to populations including children (Abrahamson 1989). Since it did not include correction for the new atomic bomb survivor dosimetry, a factor of 2.5 was adopted for purposes of BRC analysis. This current, rather unsettled situation may be summarized as follows:

UNSCEAR — the 0.4 to 4×10^{-4} range, attributable largely to uncertainty in dose rate effect (factor of 2 to 10), appears to establish an internationally accepted upper bound for adult populations.

EPA — at least for the moment, the EPA is using 4×10^{-4}.

RERF — the epidemiologists most familiar with the methods, strengths and weaknesses of the principal data base, assumptions and calculational methods of the survivor study apparently find 3×10^{-4} to be the best supported number for adults.

NRC — the value 5×10^{-4}, with children included, is consistent with UNSCEAR but not applicable to workers only.

For a population that is restricted to those occupationally exposed, the NRC coefficient is not indicated. The value 4×10^{-4}, from UNSCEAR, is the maximum from a wide range and may be overly conservative for use with workers. EPA is using this value, but for members of the general public. Giving appropriate weight to the RERF position, the coefficient 3×10^{-4} appears to be the most readily defended value for present purposes. This number exceeds the ICRP-26 coefficient by a factor of 2.4, which increases the lifetime risk associated with exposure at the limit to approximately 7%.

Appendix B

Methods of Estimating Occupational Cancer Mortality Risks From External DU Photon Radiation

APPENDIX B

METHODS OF ESTIMATING OCCUPATIONAL CANCER MORTALITY RISKS FROM EXTERNAL DU PHOTON RADIATION

The purpose of this analysis is to develop dose factors d_i for converting the deep dose equivalent from DU photons, as measured by workers' personal dosimeters, to the dose equivalent delivered to organ or tissue i. These factors enable the analyst to estimate the cancer fatality risk from irradiation of the organs/tissues i using risk coefficients C_i published in UNSCEAR-1988. Calculations of the d_i are necessary to account for attenuation of the low-energy DU photons by overlying layers of tissue. The overall risk to the worker can then be estimated as the sum of the organ risks. The risk to the workforce is the sum of the individual worker risks.

Relative Photon Energy Contributions

Ten different photon energies are included in this analysis, as shown in Table B-I. Yield and specific activity data were obtained from the new radiological health handbook (PRHH 1984). Thorium and protactinium are assumed to be in equilibrium with U-238. Uranium isotopic distribution data from Table II are used. It is assumed that the dosimeters determine the dose at 300 mg/cm depth, and attenuation to that depth is neglected. Also, neglected is self absorption by the uranium compound as well as energy degradation during photon transport to the body surface.

Organ Depths

Organ depths are center of mass values from the *in vivo* counting phantom developed at ORNL (Cristy, 1989). The depths, in centimeters, are:

Lung	10	Stomach	6
Red Marrow	5	Colon	9.3
Ovary	10	Esophagus	6
Bladder	5.5	Mult. Myeloma	5
Breast	2	Remainder	4

The breasts and remainder depths were selected by the author of this analysis. The organs selected are those for which UNSCEAR-1988 provides risk coefficients in the summary table. Bone and thyroid are included in the "remainder".

Attenuation Coefficients

Attenuation coefficients for bone and water were obtained from the new radiological health handbook (HPRHH 1984). Differences between water and soft tissue are small and are neglected.

Dose Model

Let D be the dose as determined by the dosimeter. Assume D is delivered by photons of the 10 energy levels (E_k here) shown in Table B-I; f_k is the fraction of D delivered to the dosimeter by E_k (the sum of the f_k is unity). The dose delivered to the dosimeter by E_k is $f_k D$. The attenuation factor for E_k due to overlying tissues for organ i is $F_{k,i}$; the dose from E_k to organ i is $f_k F_{k,i} D$. The dose to organ i by all of the E_k is

$$D_i = D \sum_k f_k F_{k,i}$$

The total dose to organ i per unit dose D delivered to the dosimeter is

$$d_i = D_i/D = \sum_k f_k F_{k,i}$$

The number of photons/second emitted by 1 gram of DU is for each energy level the product of the photon yield per disintegration of U-238 or U-235, the fractional contributions of U-238 (0.998) or U-235 (0.002) as appropriate, and the constant 3.7×10^{10} dis/sec-Ci. For Pa-234m and Pa it was also necessary to include the branching fractions (0.9887 and 0.0013 respectively).

The fractions $F_{k,i}$ are $e^{-\mu x}$ where μ is the attenuation coefficient and x is the organ depth.

Risk Model

Let E be the number of excess cancer fatalities among a population as caused by exposure to external photons from DU, and let E_i be the fatality toll from the irradiation of organ or tissue i. If N is the number of people exposed, $d_i D$ is the average dose equivalent to organ/tissue i among these people as defined in the dose model above, and C_i is the risk coefficient for organ/tissue i, then

$$E = \Sigma_i \quad E_i$$

and

$$E_i = N \; d_i \; D \; C_i$$

The risk, in terms of deaths per person exposed, associated with the irradiation of organ/tissue i is

$$R_i^* = E_i/N = d_i D \; C_i$$

The risk, in terms of deaths per person-rem, is

$$R_i = E_i/ND = d_i \; C_i$$

The risk associated with the irradiation of all organs and tissues exposed at high doses and dose rates is

$$R^*_{ext} = \Sigma_i \quad R_i = \Sigma_i \quad d_i \; C_i$$

The factor used for converting the risk from high doses and high dose rates to the risk from high doses and low dose rates is 2.5. Thus, the risk for DU photons received chronically at high doses is

$$R_{ext} = R'_{ext}/2.5 = 0.4 \; \Sigma_i \quad d_i \; C_i$$

Results

The results of this analysis are shown in Table B-II. The fraction of the recorded dose delivered to each organ is shown in the column headed d_i. The C_i are the corresponding UNSCEAR risk coefficients. In the R_i column the risk coefficient for each organ is given as the product d_i C_i. The sum of these coefficients 2.5×10^{-4}, is the cancer fatality risk per person-rem, applicable to high doses and high dose rates, from exposure to DU photon radiation. As discussed elsewhere in this document, RERF epidemiologists are using a factor of 2.5 to correct for the dose rate effect where the dose rate is low. Use of this factor brings the DU photon risk coefficient to 1×10^{-4}, applicable to populations and to high accumulated individual doses. The UNSCEAR summary table lists the C_i for absorbed doses of 100 rad, as opposed to using a per rad basis. This report also states that zero is the most likely number of deaths unless the collective dose exceeds 10,000 person-rad. These values would limit the applicability of the coefficients to groups of 100 persons or more receiving single exposures of 100 rad or more. However, RERF epidemiologists find high dose rate doses to the red marrow as low as 10 rad to yield statistically significant results. Substitution of the 10-rad for the 100-rad dose would indicate 1000 people or more receiving 10 rad or more as the limits of applicability.

Table B-I. Relative Contribution of DU Photons to Dose at 300 mg/cm^2

Energy (keV)	Nuclide	U-238,-235 (phtns/dis)	Phtns/Sec (per g DU)	Deep Dose (fraction)
63	Th-234	3.5 %	430.4	0.369
93	Th-234	4	491.9	0.422
765	Pa-234m	0.3	36.5	0.031
1001	Pa-234m	0.6	0.01	0.063
100	Pa-234	0.065	8.0	0.007
700	Pa-234	0.032	3.8	0.003
900	Pa-234	0.091	11.2	0.010
143	U-235	11	17.4	0.015
185	U-235	54	85.5	0.073
204	U-235	5	7.9	0.007

Table B-II Cancer Fatality Risk per Rem Delivered to Dosimeter by DU

Organ	d_i	C_i	R_i
Breast	0.739	6×10^{-5}	4.4×10^{-5}
Bladder	0.419	3.9×10^{-5}	1.6×10^{-5}
Stomach	0.396	1.3×10^{-4}	5.1×10^{-5}
Esophagus	0.396	3.4×10^{-5}	1.4×10^{-5}
Red Marrow	0.236	9.7×10^{-5}	2.3×10^{-5}
Mult. Myeloma	0.236	2.2×10^{-5}	0.5×10^{-5}
Colon	0.240	7.9×10^{-5}	1.9×10^{-5}
Lung	0.212	1.5×10^{-4}	3.2×10^{-5}
Ovary	0.212	3.1×10^{-5}	0.7×10^{-5}
Remainder	0.4	1.1×10^{-4}	4.4×10^{-5}

High Doses, High Dose Rates: $R'_{ext} = \Sigma R_i = 2.5 \times 10^{-4}$

High Doses: $R_{ext} = R'_{ext} / 2.5 \times 10^{-4}$

Appendix C

Toxicity of Tungsten

APPENDIX C

TOXICITY OF TUNGSTEN

This Appendix reviews studies reported in the literature on the toxicity of tungsten.

Abstract

Tungsten toxicity, as measured by oral LD_{50}, is greatest for soluble tungsten compounds, but varies according to species. The oral LD_{50} for mice exposed to sodium phosphotungstate is 240 ± 13.5 mg/kg while rats have an oral LD_{50} of 1,190 ± 129.5 mg/kg. Sodium tungstate has an oral LD_{50} of 875 mg/kg in rabbits.

Dose-related declines in food intake and decreased weight-gain have been reported in rats receiving dietary tungsten exposure with the greatest of these effects observed in females. Sodium tungstate fed to rats lowers blood cholinesterase while rabbits, similarly treated, show decreased sulfhydryl concentrations in blood and serum; blood glucose levels are 20-25% higher than controls in tungsten fed rabbits one hour after intravenous galactose loading[1].

Inhalation and intratracheal exposure of tungsten to animals usually produces lung irritation similar to that produced by "inert" dust. However, different inhalation experiments utilizing soluble tungsten compounds have demonstrated a variety of lung-tissue component responses. Rats exposed to tungsten silicide by inhalation and by intratracheal administration for 6 months developed hyperplasia of the lymph nodes, increased collagen in the lungs, and sporadic thickening of the alveolar walls.

---

[1]The reports of tungsten interference with cholinesterase levels in the blood, and presumably throughout the system of exposed animals coupled with the reported symptomology of tunsten workers (see this review) suggest that tungsten may be responsible for acetylcholine accumulation as is observed in organophosphate poisoning. Accumulation of acetylcholine is believed to be responsible for the tension, anxiety, restlessness, headache, imsomnia, neurosis, emotional instability, apathy, tremor, ataxia, convulsions, and depression of respiratory and circulatory centers. The reports of tungsten actions on ictal activity and glutaminase further suggest a neurological bias in tungsten health effects.

C.1 PHARMACOKINETICS

C.1.1 Inhalation Exposure And Distribution

Inhalation studies with ^{181}W-tungstic oxide in beagle dogs were reported by Aamodt (1975). Following inhalation, 60% of the inhaled activity was deposited in the respiratory tract. Of this about one-half was located in the lower portion of the tracheobronchial compartment and in the pulmonary compartment. Blood measurements indicated that inhaled tungstic acid entered the blood soon after inhalation and was removed rapidly. Measurements of selected organ and tissue samples at sacrifice (165 days post-inhalation) showed the highest test concentration of tungsten to be in lungs and kidney. Bone, gall bladder, liver, and spleen were reservoirs of tungsten by a factor of 10 less than the lung while the tungsten activity in the remaining organs decreased in the order, testes, pancreas, large intestine, small intestine, diaphragm, stomach, heart, and skeletal muscle. In terms of total organ burdens most of the tungsten actively was found in bone (37%), lung (31%), kidney (15%), liver (9.7%), and skeletal muscle (5.7%).

C.1.2 Oral Exposure And Distribution

Oral administration of ^{181}W labeled sodium tungstate to rats resulted in the greatest concentration of tungsten to be found in the spleen followed, in descending order of concentration, by kidney, pelt, bone, and liver. (Ballou 1960). Kaye (1968) who orally administered ammonium tungstate and sodium tungstate in KOH to rats reported the concentration of tungsten in the bone to be ten times that of the spleen which contained the next greatest activity. Other organs with significant tungsten concentrations in this study, in order of decreasing concentrations were hair, kidney, pelt, and liver. Twenty-four hours following administration of sodium tungstate by gastric intubation in rats Fleischman, et al. (1966) found the highest concentrations of tungsten was found in kidney followed by bone, spleen, and seminal vesicles.

Kinard and Aull (1945) described the distribution of tungsten in rat tissues after dietary feeding of tungsten and its compounds (tungstic oxide and sodium tungstate equivalent to 0.1% tungsten, ammonium-p-tungstate equivalent to

0.5% tungsten, tungsten metal at 2 and 10% tungsten) during a 100 day experimental period. This investigation indicated that bone and spleen were the major sites of tungsten deposition. The concentrations ranged from 8 to 18 mg % in bone and from 2 to 14 mg % in the spleen with averages of 11.5 and 7.5 mg %, respectively. Only traces of tungsten (less than 1 mg per hundred milligrams of tissue) were present in the skin, kidney, and liver. The blood, lungs, testes, and muscles showed traces of tungsten only in some cases. Except for a single instance for each organ, the brain heart and uterus were free of tungsten. The investigators concluded that there were no marked differences among the distribution patterns of the various tungsten compounds tested. However, since the doses of tungsten administered as various tungsten compounds were not comparable, this conclusion may not be valid.

C.1.3 Exposure By Injection And Distribution

Scott (1952) reported the greatest concentration of activity in the kidney one-day after intravenous injection of ^{181}W-sodium tungstate in rats. Other tungsten retaining tissue, in order of descending tungsten concentrations, were liver, spleen, and small intestine. Bone showed little activity. However, Fleishman et al. (1966) found that bone showed the highest tungsten concentration 24 hours following intraperitoneal injection of ^{181}W-sodium tungstate in rats. In the experimental results reported by Fleishman et al. (1966) kidney, seminal vesicle, and spleen followed bone in order of descending concentrations of tungsten retained.

C.1.4 Biological Half-Time

In the study by Kaye (1968), elimination of gastrically administered tungsten from the rat was very rapid, with a biological half-time of about 10 hours for the initial fast component of the elimination curve. Elimination of tungsten from soft tissues was relatively rapid, but a biological half-time of 44 days was observed for the spleen. The biological half-time for ^{185}W in bone was calculated to be 1100 days for the slowest component of a three-day component elimination curve.

In Aamodt's experiments (1973, 1975) 82% of injected ^{181}W-sodium tungstate was removed from rats with a biological half-time of 86 minutes, 15% with a half-time of 8.8 hours, 2% with a half-time of 3.65 days, and 1% with a 99-day half-time. Inhaled ^{181}W-tungstic oxide in dogs was removed with a biological half-time of a little less than 9 hours for 94% of the activity in the visceral area, with the longest half-time of 139 days for 1.6% of the activity. In the partial body measurements made over the lung area, about 69% of the activity was lost with a biologic half-life ($t_{1/2}$) of 4 hours, the next 23% with a $t_{1/2}$ of 20 hours, 4.6% with a $t_{1/2}$ of 6.3 days, and 3% with $t_{1/2}$ of 100 days.

C.1.5 Excretion

All reports reviewed (Scott 1952, Ballou 1960, Fleishman et al. 1966, Kaye 1968, Aadmodt 1973, 1975) agree that much of the absorbed tungsten is rapidly excreted in the urine. Kaye (1968) found that 40% of the administered dose of ^{181}W was excreted by the kidney in the first 24 hours, but very little was excreted in the urine thereafter. An additional 40% of the administered dose recovered from the feces in the first 24 hours is likely to have been largely unabsorbed tungsten together with tungsten removed in the gut with intestinal secretions and bile. By the end of 3 days, fecal elimination had accounted for 52% of the administered does.

Following intravenous administration of ^{181}W-sodium tungstate in beagle dogs, 91% of the injected activity was excreted in the urine within 24 hours (Aamodt 1973). The ratio of activity excreted in the urine to that eliminated in the feces averaged 38. While loss from the blood during the first 24 hours was very rapid, it was calculated that some of the tungsten, perhaps that bound to red blood cells or to plasma proteins, was not filtered from the plasma, or was being reabsorbed from the glomerular filtrate. The rate of decrease in blood activity following inhalation of tungstic oxide aerosol was lower than for injected sodium tungstate, but this could be accounted for by activity entering the blood from the lung and the gut over an extended period of exposure (Aamodt 1975). The ratio of cumulative urinary excretion to cumulative fecal elimination for 165 days ranged from 0.57 to 1.8, the variation being related to differences in clearance patterns of individual dogs.

In man, trace quantities of tungsten are excreted in urine and feces. In a limited study on four normal young adults without specific exposure, the elimination of tungsten by urine and feces over 24 hour periods balanced the tungsten intake in food. The urinary excretion ranged from 2.0 to 13.0 μg tungsten per 24 hours in these four subjects in 8 estimations, fecal elimination ranged from 1.6 to 5.7 μg tungsten per 24 hours (Wester 1974).

C.2 TOXICOLOGY

C.2.1 Neurotoxicology

Sodium tungstate administered to rats at doses of 0.05 and 0.5 mg/kg caused pronounced disturbances in conditioned reflexes (Nadeenko 1966). The latent periods of sodium tungstate-treated animals were 1.6 - 1.7 seconds for bell stimulus and 2.4 - 2.7 seconds for light stimulus, compared to 0.9 and 2.0 seconds, respectively for controls. Animals given the maximum doses of sodium tungstate exhibited a larger number of extinctions of the conditional reflexes. Disturbances of conditioned reflexes were indicated by a statistically significant increase in the number of equalizing and paradoxical phase states. Nadeenko (1966) noted that the study of extinction and recovery of a conditioned response to a bell revealed a pronounced decrease in the lability of nervous processes in the cerebral cortices of 0.05 and 0.5 mg/kg dose groups. Necrotic lesions and destruction of the apical portions of the intestinal villi were also evident in these animals. Nadeenko found that tissue accumulations of tungsten were dose-dependent with the highest dosages of tungsten received resulting in the greatest tissue concentrations of the metal. These findings correlated with the physiological measurements reported and led the investigator to conclude that tungsten has a cumulative toxicity.

Karantassis (1924) reported that guinea pigs exposed to tungstate by gastric intubation developed uncoordinated movement, sudden jumps, trembling, and breathlessness. Humans exposed to tungsten dusts in occupational circumstances complained of increased headaches, dizziness, nausea, and impaired sense of smell (Vengerskaya and Salikhodzhaev 1962).

Tungstic acid is used to produce experimental epilepsy in laboratory animals (Kusske et al. 1974). The application of 0.02 ml of tungstic acid gel to the surface of a cat brain cortex gives rise to abnormal EEG activity after a 20-30 minute interval which increases and results in sustained ictal activity. The effect produced is so consistent that it has been used to produce model systems of experimental epilepsy.

C.2.2 Oral Toxicology

Kinard and Van de Erve (1940) evaluated the comparative oral toxicities of tungstic oxide, sodium tungstate, and ammonium-p-tungstate in male and female rats. Rats had 100% mortality when fed diets containing ammonium-p-tungstate equivalent to 5% tungsten, tungstic oxide equivalent to 3.96% tungsten and sodium tungstate equivalent to 2% tungsten. Tungstic oxide given at a level equivalent to 0.5% tungsten caused 80 and 66 percent mortality in males and females respectively while sodium tungstate, at the same level, caused 50 and 66 percent mortalities in males and females, respectively. In comparison, 0.5% tungsten as ammonium-p-tungstate caused no death. Sodium tungstate and tungstic oxide caused no death in concentrations equivalent to 0.1% tungsten.

Oral toxicity studies for various compounds of tungsten measuring a variety of parameters with different compounds and selected species were reported in a 1966 study by Nadeenko. For sodium phosphotungstate, an LD_{50} of 240 $\pm$ 13.5 mg/kg for mice and an LD_{50} of 1,190 $\pm$ 129.5 mg/kg for rats was determined. Similar studies were reported for tungstic oxide, but the conclusions are not clear, possibly because of problems in translating the Russian text. Nadeenko (1966) does conclude that tungstic oxide is less toxic than sodium tungstate and sodium phosphotungstate because of its lower solubility. In a separate series of these experiments Nadeenko (1966) determined the sodium tungstate oral LD_{50} for rabbits and guinea pigs to be 875 mg/kg and 1,152 mg/kg respectively.

Nadeenko (1966) also studied the effect of (presumably daily) oral doses of sodium tungstate (10, 25, 50, and 100 mg/kg) on physiologic functions and systems in rats and rabbits. All doses produced growth retardation and lowered blood cholinesterase activity in rats: in rabbits the sulfhydryl concentrations

of whole blood and serum were decreased and synthesis of glycogen in the liver was disturbed. Stained sections of the gastrointestinal tract and kidneys showed signs of increased vascular permeability, hemorrhages, degenerative dystrophic changes, and moderate proliferative cellular reaction. No distinction in these biological effects was indicated with respect to sex. During the chronic phase of these studies, rabbits receiving sodium tungstate doses of 5.0 and 0.5 mg/kg had concentrations of blood glucose at levels of 20-25% higher than controls one hour after intravenous galactose loading.

Kinard and Van de Erve (1940) noted dose-related declines in food intake accompanied by decreased weight gain in dietary tungsten studies. The greatest decrease in weight gain noted in these experiments was for female rats.

C.2.3 Pulmonary Toxicology

In both short- and long- term animal experiments, the major effects of inhalation or intratracheal exposure to tungsten and its compounds have been reported as limited to the respiratory system. Menzentseva (1967) reported that lungs of rats exposed by inhalation to tungsten carbide at 600 mg/m^3, 1 hour/day, for 5 months showed proliferative reactions to the lymphoid histiocytic elements and uniform thickening of the alveolar walls followed by mild fibrosis. Mezentseva (1967) also reported that rats given single intratracheal doses of 50mg of either metallic tungsten, tungsten carbide, or tungsten trioxide showed no severe pulmonary changes under microscopic examination.

Delahant (1955) reported that neither metallic tungsten nor tungsten carbide given intratracheally to guinea pigs irritated lung tissue. Similarly, Miller et al. (1953) observed mobilization of septal cells; engulfment of pigment; and accumulation of air sacs, lymphoid tissue and alveolar walls in rats given 10% suspensions of tungsten intratracheally in a manner typical of those effects produced by inert dust.

However, Schepers (1955) found that intratracheal injection of tungsten carbide and carbon in weekly doses of 50 mg of a (94:6) mixture caused acute hyperemia and bronchial inflammation in guinea pigs. Minor residual changes such

as the development of subpleural fibrocellular granulomata, were also noted in the lungs. Brakhnova and Samsonov (1970) reported that inhalation and intratracheal exposure of rats to tungsten silicide of 1-6 months caused hyperplasia of the lymph nodes, sporadic thickening of the alveolar walls, and increased collagen in the lungs. These results suggest that tungsten and some of its compounds, such as those most frequently encountered in the cemented tungsten carbide industry, have distinctive toxicities.

C.3 BIOCHEMICAL TOXICOLOGY

C.3.1 Potential Teratogenic Effect

Tungsten is the element most chemically similar to molybdenum and is the only substance known that is capable of producing experimental molybdenum deficiency in animals. This is accomplished by tungsten's ability to replace molybdenum in sulfite oxidase and to prevent the incorporation of molybdenum into xanthine oxidase. In the case of xanthine oxidase, inactive apoprotein is synthesized when WO_4^{-2} is fed (Johnson et al. 1974), but in the case of sulfite oxidase up to 35% of the molybdenum-free enzyme contains tungsten. (Cohen et al. 1974). Cardin and Mason (1976) concluded from their studies that the gastrointestinal absorption and transport of molybdate are sufficiently non-specific to accept tungsten over molybdenum.

In humans, genetic deficiency of xanthine oxidase appears to be relatively harmless (Watts et al. 1964). Therefore the ability of tungsten to interfere with the activity of this enzyme by preventing the incorporation of molybdenum has not been shown to constitute a serious toxicological condition.

However, in the case of sulfite oxidase, the potential for serious complications arising from tungsten exposure in such a way as to affect sulfite oxidase has been observed (Cohen et al. 1974). A fatal case of sulfite oxidase deficiency has been reported in a human patient (Irrevere 1967). The patient was born with neurological abnormalities and deteriorated to a virtual decorticate state by 9 months. Bilateral ectopia lentis was discovered at 1 year. The patient was studied at the age of 30 months. Urine was found to contain

abnormally increased amounts of 5-sulfo-L-cysteine, sulfite, and thiosulfate. Urinary excretion of inorganic sulfate was markedly reduced and did not increase after administration of L-cysteine. These chemical abnormalities were best explained by the presence of a block to conversion of sulfite to sulfate. Studies from tissues obtained from the patient in post-mortem revealed a marked deficiency in sulfite oxidase.

Cohen et al. (1974) reported that the development of both sulfite oxidase and xanthine oxidase is very much impaired by the administration of tungsten to pregnant rats 20 days before birth of the litter. Creation of simultaneous deficiencies of sulfite oxidase and xanthine oxidase in adult rats by administration of tungsten has no observed deleterious effects on these animals, but does render them highly susceptible to toxicity from bisulfite and SO_2 (Johnson et al. 1974). Apparently, normal development of sulfite oxidase leads to the accumulation of inactive molecules in the livers of offspring of tungsten fed rats. Development of succinate cytochrome c-reductase and adenylate kinase is not affected by tungsten treatment.

C.3.2 Direct Enzyme Action

Sodium tungstate has been shown to activate brain glutaminase increasing ammonia release, in contrast to ammonium molybdate which inhibits it. (Johnson et al. 1974). The tungsten activation is believed due to either elevation of phosphorus ion concentration in the brain or to activation of glutaminase by direct action on the molecule (Bech 1974).

C.4 CARCINOGENESIS (POTENTIAL)

Studies utilizing molybdate, tungstate, and vanadate have revealed that these agents block the transformation of cytosol-steroid complexes to their activated form (no effects of these compounds have been reported on an activated steroid receptor). Because these agents are potent phosphatase inhibitors it has been suggested that the process of steroid receptor activation involves a dephosphorylation of the receptor protein itself or of a regulatory component. Recent studies have indicated that sodium molybdate not only blocks the activation of the steroid receptor complex, but also blocks the DNA and nuclear

binding capacity of activated rat liver glucocorticoid-reception complex. In a subsequent study tungstate was found to be able to extract the DNA-cellulose bound glucocorticoid-receptor complex at even lower concentrations than those shown to block binding-capacity by molybdate (Murakami et al. 1982). The significance of these enzyme-metal interactions may be important with respect to the development of lymphosarcoma. One of the critical actions of the glucocorticoid hormones is their ability to arrest the development of certain tumors of lymphatic origin. In vitro, glucocorticoids inhibit the growth of lymphosarcoma cells and mouse fibroblast. Specific glucocorticoid binding protein present in the cytoplasm and nuclei of steroid-sensitive cells are reduced in amount in resistant cell lines (Goldstein, Arnow, and Kalmar 1974). Thus, in conditions favoring the initiation of lymphatic tumor growth, exposure to sufficient tungstate may be capable of overwhelming the glucocorticoid actions which inhibit this neoplasia via mechanisms described above in the interactions with the cytosol-steroid complexes and/or the DNA and nuclear binding capacity of the activated glucocorticoid reception complex.

C.5. CHEMICALLY INDUCED ESOPHAGEAL AND FORESTOMACH CARCINOGENESIS

Tungsten has been observed to reverse other cancer-inhibiting reactions. In chemically-induced carcinogenesis studies, tungsten added to the drinking water (200 ppm) of male rats countered the inhibitory effect of molybdenum on NSEE-induced esophageal and forestomach carcinogenesis (Luo et al. 1983). Whether similar effects may also occur in humans remains to be investigated. Epidemiologic data indicate that breast cancer mortalities among the residents of tungsten-mining areas in China are markedly higher than the national average. However, no information on the tungsten intake from water and food in the tungsten-mining area, nor on the estrous cycle of women residing in high molybdenum-intake areas, is available at this time (Wei et al. 1985).

Appendix D

Quantification of Occupational, Military and Environmental Health Risks Associated With the Military Life Cycle of DU Kinetic Energy Penetrators

APPENDIX D

QUANTIFICATION OF OCCUPATIONAL, MILITARY AND ENVIRONMENTAL HEALTH RISKS ASSOCIATED WITH THE MILITARY LIFE CYCLE OF DU KINETIC ENERGY PENETRATORS

In this section an attempt is made to develop scenarios to quantify the health risks arising from exposure to DU in occupational, military and environmental settings associated with the manufacture, use and recycling of DU kinetic penetrators. A similar quantitative health risk assessment for W kinetic energy penetrators is not possible with the information currently available.

Despite the fact that a side-by-side quantitative comparison of DU and W health risks cannot be made at present, comparisons can be drawn between occupational, military and environmental exposures to DU and background concentrations of U and background radiation levels. This will allow one to place the health risks associated with continued use of DU in the kinetic energy penetrator ordnance program in quantitative perspective.

The occupational health risks are based on empirical exposure data gathered from actual DU manufacturing environments. The military health risk calculations are based on representative worst-case test-firing and combat exposure scenarios. The environmental health risk calculations are based on upper bound worst-case screening level exposure scenarios.

When comparable data become available for tungsten, a similar quantitative analysis can be performed and a side-by-side quantitative comparison made.

D.1 NATURAL OCCURRENCE, TRANSPORT-FATE AND DISTRIBUTION OF DU IN TERRESTRIAL AND AQUATIC ECOSYSTEMS

D.1.1 Terrestrial Ecosystems

Natural background levels of U in a Russian study were on the order of 0.5 mg/kg (JTCG/ME 1974). The worldwide average is said to be 2 mg/kg (Magness 1985). In a Russian study, the highest reported organism/soil concentration factors for plants, grasses, and sheep were 0.24, 0.082 and 0.22 respectively

(JTCG/ME 1974). In a study of small mammals at a test range, tissue/soil ratios in the range 10^{-3} to 10^{-4} were measured, although the mean U levels in the gastrointestinal tract were more than 10 percent of soil concentrations.

The solubility of either U(IV) or U(VI) is governed by the pH, pE, counter ion concentrations and ligand concentrations in the water. The molar solubility of all U species appears to range between 10^{-6} and 10^{-4} in the ranges of pH, pE and phosphate and carbonate ion concentrations likely to be encountered in soil pore water, for example (Muller and Duda 1985). A 10^{-4} molar solution is equal to 0.0235 g/L or 23.5 mg/L.

The affinity of U for soil particle surfaces (sorption) is governed by many of the same factors as solubility, but here the composition of soil particles also becomes important. In the presence of bicarbonate solutions, the sorption of uranyl ion on clays is reduced, due to aqueous complexation with carbonate ion, reducing the maximum soil:water partition coefficient values for tested illite and montmorillinite samples to 110 and 2 L/kg, respectively. In the presence of dissolved carbonate at concentrations between 10^{-3} and 10^{-2} molar and pH > 6.5, U sorption is virtually precluded on all the ferric oxide species tested (Erickson et al. 1989). At lower pH the sorption of U(VI) on amorphous ferric hydroxide yielded a Kd value of 3×10^{4} L/kg. The authors conclude that dissolved carbonate present in concentrations found in ground water under unfavorable pH could significantly inhibit the retardation of U due to this carbonate complexation phenomena, since Kd is proportional to retardation.

Measured Kd values for soil and pond sediment, and soil, at the two Aberdeen and one Yuma test facility sites, respectively, are reported to be 4360 +/- 260 L/kg and 328 +/- 20 L/kg, and 54 +/- 3 L/kg, respectively. This latter value reflects the nature of the Yuma soils, which are sandy with little clay content. These data are site specific and cannot be applied elsewhere.

An alternative method for estimating the spatially-averaged subsurface soil:pore water partition coefficient is to assume that the concentrations of U in subsurface soil pore water are in equilibrium with natural background levels in soil. The concentration in ground water at the Lake City test site was

nondetectable at 0.27 μg/L (Boldt 1988). This indicates that solubility and sorption processes can limit aqueous uranium concentrations to below detection limits.

D.1.2 Aquatic Ecosystems

Natural background levels of U in U.S. waters range from 5×10^{-7} g/L for rivers draining watersheds with primarily igneous rocks and clay, and 2×10^{-4} g/L from carbonate rocks. Natural background levels in sediments are on the order of 0.2 to 1.2 mg/kg (JTCG/ME 1974).

Aquatic plants that favor marsh conditions have been demonstrated to concentrate U from water in the range 10^{-4} to 10^{-1} (JTCG/ME 1974). U is decreasingly concentrated up the aquatic food chain. Thus, biomagnification will not occur with DU.

D.2 METHODOLOGICAL APPROACH

D.2.1 Inhalation Risks

For public inhalation exposures, 75 percent of the suspended particles is assumed to be of respirable aerodynamic diameter (< 10 microns), with 25 percent deeply respired, 50 percent deposited in the nasopharyngeal region or tracheobronchial region, and 25 percent exhaled. The particles deposited in the nasopharyngeal and tracheobronchial regions are assumed to be swallowed, along with an additional 50 percent of the 25 percent exhaled that is assumed deposited in the upper pulmonary region and bronchae during exhalation and reintroduced into the throat by the action of the ciliary escalator, for a total of 62.5 percent swallowed and 25 percent deposited in the lower pulmonary region (ICRP 1968).

In the absence of source-, species-, and site-specific data, generically 50 percent of the DU is assumed to be soluble and 50 percent insoluble. This is consistent with the assumption made in the occupational risk assessment. Only 5 percent of the swallowed soluble DU is assumed to be absorbed by the gut (ICRP 1979). The average individual is assumed to respire at a rate of 23 M^3/day

(ICRP 1981), to be located in the vicinity of a primary residence 16 hrs/day, 7 days/wk, 50 weeks/yr, for 70 years. To compare these risks to occupational and military personnel risks, an 8 hr/day, 5 day/wk, 50 wk/yr exposure is assumed for a 20 year working lifetime.

In the absence of specific ambient suspended particle concentration data, where exposure is due to wind resuspension of contaminated particles, for military personnel exposures the ambient total suspended particle (TSP) concentration will be assumed for purposes of estimation to be 0.25 mg/M^3, the instantaneous maximum TSP air quality limit, while for public exposures the concentration will be assumed to be 0.06 mg/M^3, the annual average TSP air quality limit. All of the suspended particles are assumed to originate with the contaminated soil. This is a conservative assumption that provides a margin of safety that increases with the distance from the source area, due to the increasing contribution of background sources to the suspended particle concentration as one moves away from the source.

D.2.2 Drinking Water Exposures

For the long term lifetime increased cancer risks associated with drinking DU-contaminated water from a hypothetical drinking water well 5 km from the target impact point, it is assumed that an individual consumes 2 L/day of water, 7 days/wk, 50 wks/yr for 70 years. Only 5 percent of the soluble DU in the drinking water is assumed to be absorbed via the gut (ICRP 1979).

D.2.3 Sediment Exposures

Since DU does not bioaccumulate to any significant extent, and since the bioavailability of DU via the ingestion route is quite low, the sediment exposure route is of little consequence. While some USEPA Superfund-sponsored risk assessments have considered direct ingestion of sediment as a viable route of exposure for a small child (e.g., Fields Brook Feasibility Study, CH2M Hill 1985), the risks associated with drowning for an unattended toddler are far greater than those associated with direct ingestion of sediments. As such, this latter exposure scenario will be given no credence in this risk analysis.

If the concentrations accumulated in sediment are determined to be significantly above background levels, the external radiation cancer risk to the extremities will be calculated for an individual wading in the river with bare feet for a period of 4 hr/day, 3 days/wk, 50 wks/yr for a 70 yr lifetime.

D.2.4 Radiation Hazard Factors

For purposes of this risk analysis, the following lifetime increased cancer risk and conversion factors will be used:

	Internal Risk Factors	Conversion Factor
Soluble DU	3×10^{-4} per rem	5 rem/1×10^{-6} Ci
Insoluble DU	3×10^{-4} per rem	5 rem/0.04×10^{-6} Ci

These are the high dose dose-response factors for lifetime increased cancer risk. A correction factor of 2.5 could be used to reduce the potency for the chronic, low dose exposure (RERF 1988), but this was not done, in order to ensure that the radiation risk estimates, even for low dose, chronic exposures, are upper bound values.

For external radiation exposure, a risk factor of 1×10^{-6} cancers/rem-yr to the skin of the extremities and 5×10^{-6} cancers/rem-yr to the bone of the extremities is used.

D.2.5 Chemical Toxicity Hazard

The radiation risks associated with DU exposure generally determine the acceptable exposure levels in all media, except in the occupational environment, where risks on the order of 10^{-4} to 10^{-3} are accepted routinely and as high as 10^{-2} for certain substances and circumstances. The chemical toxicity hazard of DU in the occupational environment is discussed in Section 2.1.2 of this report.

D.2.6 Calculated De Minimus Risk Levels

Using the above exposure scenarios and DU radiation risk factors, concentrations in water, air and soil corresponding to a 10^{-6} *de minimus* lifetime increased cancer risk can be calculated for occupational/military or public MEIs. For water, the 10^{-6} risk level is calculated as follows:

[Z mg/L] x 0.05 absorbed x 4.3×10^{-10} Ci/mg x 5 rem/1 x 10^{-6} Ci x 3 x 10^{-4} cancers/rem-yr x 2 L/day x 7 days/wk x 50 wks/yr x 70 yr = the lifetime increased cancer risk

[Z mg/L] x 1.58×10^{-3} = the lifetime increased cancer risk

For a 10^{-6} *de minimus* risk level:

[Z mg/L] = 10^{-6} / 1.58×10^{-3} = 6.3×10^{-4} mg/L

This is about half the chemical toxicity hazard level of concern for the 10 kg child derived above.

For the occupational/military inhalation exposure scenarios described above, the 10^{-6} risk level in air is:

[Y mg/M3] x 23 M^3/day x 8 hrs/24 hrs x 5 days/wk x 50 wks/yr x 0.75 x [(0.625 x 0.05 + 0.25) x 0.5 x 4.3×10^{-10} Ci/mg x 5 rem/1 x 10^{-6} Ci + 0.25 x 0.5 x 4.3×10^{-10} Ci/mg x 5 rem/0.04 x 10^{-6}] x 3 x 10^{-4} cancers/rem-yr x 20 yrs =

[Y mg/M3] x 5.9×10^{-1} = lifetime increased cancer risk

For a *de minimus* risk of 10^{-6}:

[Y mg/M^3] = 10^{-6} / 5.9×10^{-2} = 1.7×10^{-5} mg/M^3

A similar calculation is carried out for an ambient inhalation exposure for the general public, except that the number of hours of continuous exposure is increased to 16 hrs, the number of days of exposure per week is increased to 7, and the number of years of continuous exposure is increased to 70. The resultant airborne particulate concentration corresponding to a 10^{-6} *de minimus* risk is 1.7×10^{-6} mg/M^3.

Corresponding levels in the soil are 68 mg/kg and 28 mg/kg, respectively, calculated assuming all of the resuspended particles are of contaminated soil origin, as described above.

Risk Perspective

To place these risks into perspective, it should be kept in mind that the background risk from all radiation sources is about 1.8×10^{-3}. The U.S. Environmental Protection Agency generally considers *de minimus* risk to lie somewhere between 10^{-7} and 10^{-4}, with 10^{-6} usually triggering a threshold of concern for individual chemicals. Some States (e.g., Minnesota, Michigan, and Wisconsin) have adopted 10^{-5} acceptable lifetime increased cancer risks as *de minimus* when regulating surface water discharges and 10^{-6} when regulating ground water discharges and cleanups, with the rationale for the differential associated with the more rapid recovery times for surface waters vis-a-vis ground waters.

D.3 QUANTIFICATION OF OCCUPATIONAL HEALTH RISKS ASSOCIATED WITH DU KINETIC ENERGY PENETRATOR MANUFACTURE

For purposes of risk quantification on an exposed population basis, the number of exposed workers in a typical projectile-production facility is assumed to be 260. To estimate the cancer fatality risk to this group from DU inhalation it is necessary to adjust the risk percentages given in Table 2-5 according to actual exposure conditions including the number of years of exposure, actual intakes and to differences in the particle size distribution between actual conditions and those assumed in the development of the uranium inhalation standards.

The airborne DU concentrations to which these workers are exposed are estimated at 5 to 10 percent of the regulatory concentration values, reducing the risk from 7 percent to the range 0.35 to 0.7 percent. Assuming that these people continue in this work for 20 years rather than 50 as assumed in the determination of the limits, the risk range is reduced by 20/50 to 0.14 to 0.28 percent. Deposition in the tracheobronchial region is independent of the Activity Median Aerodynamic Diameter (AMAD) over the size range in question. With respect to the pulmonary region, consideration of the actual AMAD, 6 to 10μm, rather than 1μm AMAD, as assumed in the calculation of the standard, reduces the lung dose by factors of 0.3 (7 percent/24 percent) and 0.2 (5 percent/24 percent) respectively, an average reduction of 0.25 is applicable. If Class D DU only is involved, it must be recognized that essentially all of the DU that is not exhaled enters the bloodstream irrespective of particle size. For an AMAD of 6μ rather than 1μm the doses to the organs are increased. With a 6μm-AMAD 10 percent of the DU particles are exhaled, whereas with a 1μm-AMAD 39 percent are exhaled. This increases the organ doses by a factor of about 1.5. Indications are that Class D and Y materials are about equally distributed in projectile-production areas. Under these conditions half of the risk is reduced by a factor of 0.25 while the other half is increased by a factor of 1.5. These considerations change the risk range to 0.12 percent to 0.24 percent.

The estimated number of fatalities for the 260 workers working an average of 20 years lies in the range 0.3 to 0.6.

Workers engaged in the manufacture of DU projectiles are normally exposed to DU concentrations in air of 1×10^{-11} μCi/ml. The particle size distribution is 6 to 10μm AMAD. Larger AMADs protect the pulmonary region, but fewer particles are exhaled. If the additional particles deposited in the nasopharyngeal and tracheobronchial regions are highly soluble, more DU will enter the bloodstream. Using the higher value of 10μm, 98 percent of the inhaled DU reaches the bloodstream as opposed to 61 percent if the AMAD is 1μm, a factor of 1.6 increase. If R is the chemical toxicity risk associated with exposure at the regulatory limit, the DU worker risk is about 0.2 R (1.6/8.6). Even if the nephrotoxic limit for man is actually 0.6 rather than 3 ug U/g kidney, it is

concluded that DU workers would still be below the kidney damage threshold. Since the AMAD is often less than 10μ, the concentration in air is often less than 1×10^{-10} μCi/ml, and since not all DU is highly soluble, this conclusion has an ample margin of safety.

D.3.1 Skin and Extremity Exposures

The estimated dose to the skin of DU workers, other than the skin of the extremities, is about 2.5 rem/year. The current regulatory limit is 7.5 rem/quarter, or 30 rem/year. This limit is being increased to 50 rem/year in accordance with ICRP and NCRP recommendations and in compliance with new Presidential Guidance to Federal Agencies.

The estimated dose from DU to the skin of the extremities is about 6.8 rem/year. The current NRC regulatory limit is 18.75 rem/quarter to this skin, or 75 rem/year which is also in the process of being changed to 50 rem/year.

The risk coefficient for fatal skin cancer (melanoma) is 1×10^{-6} fatalities/person-rem. Assuming that 260 workers remain in DU work for 20 years, the estimated number of fatalities is

$$260 \text{ persons} \times 6.8 \text{ person-rem/yr} \times 20 \text{ yrs} \times 1 \times 10^{-6} \text{ fatalities/person-rem} = 0.035$$

The best interpretation of this result is that no fatalities would occur.

The average annual whole-body dose to these workers from photons is 0.15 rem, or 3 rem during a 20-year period. Thus, the 20-year dose to the extremity bone may be estimated as 12 rem if it is assumed that the radiation source is near the hands and that the photon dose rate there is a factor of 4 greater than at the surface of the trunk. The risk coefficient for the bone is 5×10^{-6} fatalities per person-rem. The fatality estimate is

$$260 \times 12 \text{ person-rem} \times 5 \times 10^{-6} \text{ fatalities/person-rem} = 0.016$$

Again, the best estimate is zero.

D Combined Risks

The radiobiological risk from DU inhalation, discussed in Section 2.1.2.1, i: lculated to be 1.2×10^{-3} to 2.4×10^{-3} cancer fatalities per person de; :ing upon the DU concentration in air. The mean is 1.8×10^{-3}.

The chemical toxicity risk discussed in 2.1.2.2 may be taken as zero since exposures are below the threshold for chemical damage to the kidney, even if a nephrotoxic limit of 0.6 µg U/g kidney is used rather than the current 3 µg U/g kidney.

The radiological risk from external DU photons to all body organs other than the bone and skin of the extremities is indicated in 2.1.2.3 to be 3×10^{-4} fatalities per person.

The radiobiological risk from exposure of the skin to beta radiation and photons (using the average dose to the skin of the extremities) is indicated in Table 1-5 to be 1.4×10^{-4} fatalities per person.

The radiobiological risk from exposure of extremity bone, from Table 1-5 is calculated to be 6×10^{-5} fatalities per person.

The sum of these potential risks is 2.3×10^{-3} fatalities per person. When multiplied by the 260-person workforce, the number of fatalities is less than one.

D.4 QUANTIFICATION OF MILITARY HEALTH RISKS ASSOCIATED WITH THE USE OF DU KINETIC ENERGY PENETRATORS IN NON-COMBAT AND COMBAT SITUATIONS

In non-combat situations the highest rates of external exposure to DU radiation occurs in loading and unloading pallets or shipping boxes containing the ordnance, particularly loading and unloading storage lockers, while the highest rates of exposure to elemental U occur during test-firing-related activities.

In combat situations, the highest rates of exposure to external radiation occur to the soldier nearest to the kinetic penetrator ammunition storage rack in a tank, while the highest rates of internal exposure to DU radiation and chemical toxicity occur during the occupancy of a disabled tank by a soldier seeking to use the disabled vehicle as shelter. Secondary exposures to resuspended DU particles generated in the fragmentation of kinetic penetrator rounds fired at enemy tanks must also be evaluated.

D.4.1 Non-Combat Military Health Risks

D.4.1.1 Source Quantification

Shipping of Test Rounds

Rounds are packed in fiber containers, two to a box, with 15 boxes per pallet (Pierre Committee 1978). The maximum radiation flux reported at the surface of a finished shipping container was 0.77 mR/hr (Pierre Committee 1978). Data published by Battelle (1987) indicate that the maximum DU radiation exposure in a storage locker situation is on the order of 3 mR/hr at the surface of the pallet or in between pallets, while the maximum radiation level at the surface of an ammunition box is about 1.2 mR/hr.

Test-Firing Exposure Quantification

Prior to the institution of semi-enclosed target facilities, efficacy testing and demilitarization activities were conducted in the open. "Between 1960 and 1975, a maximum of 61,240 rounds of 25-millimeter XM101 (Davy Crockett) ammunition was fired on the Lake City Ammunition Plant ranges (for purposes of demilitarization). Each DU penetrator weighed approximately 0.5 pounds. The largest fragments of DU were collected from the bullet-catchers, containerized, and buried in a low-level, land burial site. A conservative estimate would be that 75 percent of the DU was recovered. This would result in a 'worst case' of 7,655 pounds of DU remaining as contamination." (Smith 1988)

At present, typically twenty finished rounds are tested from each 5,000 round lot (Pierre Committee 1978).

Efficacy Testing

The results of open air test-firing at various thicknesses of armor plate at 90° and 45° angles indicate that for the shot with the lowest percentage aerosol formation (0.5 - 1 percent), the maximum concentration of DU in the dust cloud carried by a 25 mph wind to a distance of 500 M was 66 $\mu g/M^3$. The maximum concentration on fallout plates at the same distance was 0.3 $\mu g/100\ cm^2$, while the maximum concentration within 30 M of the armor plate target was 1840 $\mu g/cm^2$. For a test shot in which 25 percent of the penetrator was aerosolized, the corresponding maximum concentrations on fallout plates were 0.7 $\mu g/100\ cm^2$ and 650 $\mu g/cm^2$ at 500 M and 30 M, respectively, and 4.4 $\mu g/M^3$ in the passing dust cloud at 500 M. The highest concentration within 30 meters of the 12 test shots was 17,500 $\mu g/cm^2$. No more than 86 percent of the KP mass was recovered in any of the 12 test shots (Wilsey and Bloore 1982).

Enclosed efficacy testing data on aerosol formation and distribution within the test butt were collected by Chambers et al. (1982). The results of the study led to the conclusion that only about 10 percent of a 2.27 kg penetrator was aerosolized upon collision with armor plate with a muzzle velocity of about 1500 M/sec. While about 70% of the particles observed by Chambers (1982) were respirable (less than 7 micrometers), and increased muzzle velocities should not result in substantial changes in the particle size distribution of respirable particles, no actual data is available on what fraction of the penetrators are aerosolized as a function of increasing muzzle velocity.

D.4.1.2. Environmental Impacts

Soil Impacts

Most of the DU fragments generated in open-air accuracy testing are larger than in corresponding efficacy testing. As a result, the production of rapidly solubilizable uranium oxide particles is much lower per square meter within the vicinity of the point of impact (Magness 1985).

Identifiable fragments of the kinetic penetrator munitions have been reported in a walk-over survey of all areas of the Lake City AAP test ranges,

including the 600-yard bullet-catcher area, the sand pile, the 75' x 200' sand pile storage area, and the 2,180-meter impact area. Radiation levels above background were not detected at the 2,180-meter impact area. The conclusion of the survey is that contamination is widespread but not homogeneous. However, additional soil sampling would be necessary to accurately characterize the nature, magnitude and extent of contamination on the entire range (Bachelor 1988).

Approximately 75 percent of the DU was accounted for within 300 M of the detonation point (Boldt 1988). Samples of upper soil layers beyond 20 M from the target were near background radiation levels (White 1981). Within this radius, only isolated pockets of excessive U concentrations were found, indicating an irregular fragmentation pattern.

More recent sampling of the Lake City AAP by Chem-Nuclear Systems, Inc. indicates contamination increases with soil depth at many of the sites tested at the range (Whittaker via Hayes 1987). At one sampling location at a depth of 6 - 9 inches a concentration of 12,600 mg/kg was detected at the six inch depth, or 7,400 times the 1.7 mg/kg background level observed.

Measured Groundwater Impacts

Ground water analyzed for DU-related radioactivity at the Lake City AAP ranges found no detectable DU at 0.1 picocurie/liter, equivalent to 0.27 μg/L using a conversion factor of 0.36 picocuries/microgram DU (Boldt 1988).

However, there is concern that the uncollected fragments will continue to slowly oxidize to soluble uranium oxides that will than slowly leach to ground water, given sufficient time. Penetration of DU in soil at test sites has not exceeded 9 inches (Whittaker 1987) and in fact may be as little as six inches, taking into account the stratification of the 6- to 9-inch depth sample. This corresponds to a maximum leaching rate of roughly 0.15 M in 30 years, or 0.005 M/yr.

Measured Surface Water Impacts

Runoff contamination of nearby watercourses has been demonstrated at several efficacy test firing areas. Results of these studies indicate that DU-contaminated particles do not stay in suspension very long, with concentrations falling to background (radiation) levels at about 5000 M. Despite the contamination of stream and pond sediments, non-detectable concentrations were reported in overlying water at a detection limit of 0.1 picocuries/liter or 0.27 μg/L (Boldt 1988).

D.4.1.3 Risk Analysis

Loading and Unloading of Storage Lockers

Assuming loading and unloading involves hand contact with ammunition boxes 50 percent of the time and hand presence between pallets 25 percent of the time, the maximally exposed military personnel involved in loading and unloading ammunition boxes from the pallets 8 hours/day, 5 days/wk, 50 weeks/yr, would receive, at most, 2.7 rem/yr.

The corresponding occupational limit for annual exposure of extremities to DU radiation is now 50 rem/yr. The health risks associated with such activities are thus an order of magnitude lower than those deemed acceptable in an occupational setting. Nevertheless, using the cancer risk factor range for exposure of extremities stated above, the lifetime increased cancer risk from 20 years of exposure would be about 5×10^{-5} to 3×10^{-4}.

Efficacy Testing

For purposes of this analysis, it is assumed that the degree of fragmentation increases linearly with the increase in kinetic energy, so that a 5 kg penetrator fired at the maximum muzzle velocity reported will fragment to yield roughly 0.008 kilograms of aerosol in the reflection collector pipe. If the target strike overpressure carries an equal amount into the environment and 50 percent is deposited within 500 M, while 50 percent remains suspended in a slowly dispersing cloud with a volume of 10 M x 10 M x 10M at 500 M, then assuming the cloud passes the MEI over a period of 30 seconds in a moderate

breeze, the maximum concentration in air at the 500 M mark is 4 mg/M^3 following each shot and the daily average concentration for 20 shots is reduced by a factor of

0.5 min/(60 min/hr x 8 hr) = 2.08×10^{-2}, or 8.3×10^{-2} mg/M^3.

Based on the occupational air concentration corresponding to a 10^{-6} risk of 1.5×10^{-5} mg/M^3, the lifetime increased cancer risk from such an extreme exposure for the MEI is 5.5×10^{-3}. This is roughly twice background radiation risks. More realistic exposure scenarios would involve correspondingly lower lifetime increased cancer risks.

If cloud dispersion is such that the volume doubles with each 500 M of passage, and resuspension is assumed to equal deposition, then the risk to the public at 5 km will be 1.8×10^{-5} excess cancers in a lifetime. This is about two orders of magnitude less than the lifetime increased cancer risks associated with background radiation exposures from all sources. However, the above assumes that the wind is always blowing in the same direction, 8 hours per day during testing. More realistic exposure scenarios (e.g., the use of a typical wind rose) and transport assumptions (e.g., deposition of particles is greater than resuspension for most of the suspended particle size categories) would result in correspondingly lower lifetime increased cancer risks. The accumulation of DU particles in residential soils, even under such an extreme scenario, is expected to be negligible and the health risks associated with those accumulations even more so.

If 50 percent of the aerosolized penetrator released from the facility is deposited within 500 M of the facility in a pie wedge of ninety degrees, and the soil is mixed to a depth of 0.005 M, then the maximum concentration accumulated in the soil in the vicinity of the facility at 20 shots/day, 5 days/week, 50 weeks/yr is about 13.6 mg/kg. If one-third is wind eroded and one-third runs off, transporting the first 0.005 M of soil, and one-third leaches into the soil at a rate of 0.005 M/yr, the surface concentration will not exceed 4.5 mg/kg at the surface of the uneroded soil horizon, which is roughly double background levels.

If testing continues unabated for 100 years with no loss of DU from the surface soil (an impossible situation where wind erosion is occurring), the maximum accumulation in the vicinity of a test facility will be on the order of 1,360 mg/kg, or about 1000 times natural background levels of U in soil. If this soil is then allowed to erode under wind action, an unprotected individual standing just down wind of the contaminated area 8 hr/day, 5 days/wk, 50 wks/yr, continuously exposed to a maximum of 0.250 mg/M^3 of particles of test area origin in the air, will accrue a lifetime increased cancer risk associated with a 20 year exposure of about 2.2×10^{-5}.

Corresponding inhalation risks to the public in hypothetical residential areas 5 km distant would be correspondingly lower due to the dilution of suspended particles of site origin with particles of non-site origin, yielding a negligible lifetime increased cancer risk.

Where loss processes are occurring, the actual accumulation in surface soils will be much less, perhaps approaching the initial accumulation level in highly erodible and leaching environments. This would result in proportionally lower health risks to the military and public MEIs.

Accuracy Testing

Accuracy testing occurs in the open air with soft targets. At present penetrator fragments at most sites are not routinely collected after accuracy testing due to the risk of injury from unexploded ordnance on the test range.

For purposes of constructing a worst-case scenario, assume that 5 percent of a 5 kg kinetic penetrator is aerosolized upon impact with the target, that all of the larger fragments and 85 percent of the aerosol is deposited within 500 M of impact, that all of the deposited aerosol is solubilizable in one year and that the rate of solubilization of DU fragments in rainwater is about 1 percent per year (solubilization half-life of about 6.9 years in fresh water with rainfall occurring 10 percent of the year). After 100 years of testing, the rate of solubilization and the rate of addition of DU to the soil as a byproduct of testing are equal. The depth of penetration of leachate is a maximum of 0.005

M/yr. The ground water is assumed to be just below the surface, so that the leachate reaches ground water instantaneously. Mixing of the surface accumulation occurs to a depth of 0.005 M. Assume that one-third of the surface accumulation runs off during precipitation events and that one-third is wind eroded during dry, high wind events, leaving one-third to leach. The soil is assumed to have a bulk density of 1.5×10^3 kg/M^3.

The amount deposited on surface soil at the rate of 20 shots/day, 5 days/week, 50 weeks/yr for one year of testing is:

(5 kg x 0.05 x 0.85 x 20/day x 5 day/wk x 50 wk/yr +
5 kg x 0.95 x 20/day x 5 day/wk x 50 wk/yr x 0.01) /pi x $(500)^2$
= 1.65×10^3 mg/M^2

For a soil with a bulk density of 1.5×10^3 kg/M^3 and a mixing depth of 0.005 M, the corresponding concentration in soil initially would be 213 mg/M^3. If precipitation runoff and wind erosion carry the first 0.005 M away each year, only the material that has leached to a depth of 0.005 M will remain. If only one-third of the DU in the surface layer is leached to a depth of 0.005 M, then when the underlying surface is exposed after wind and precipitation erosion, the accumulated concentration in the surface soil layer will be one-third of the initial concentration, or 71 mg/M^3.

Assuming that testing continues for at least 100 years, a steady state will eventually be reached between the rate of leaching of accumulated fragments and the rate of addition of new aerosol and fragments. The concentration in the soil surface layer under these steady state conditions will be:

1/3 x (5.0 kg x 0.05 x 0.85 + 5.0 kg x 0.95 x 0.01 x 100 yr) x 20 x 5 x 50/ [
pi x $(500\ M)^2$ x 0.005 M x 1.5×10^3] = 1400 mg/kg

Using the one-third, one-third, one-third routing assumption for wind erosion, precipitation runoff and leaching, this is the concentration in wind-suspended particles and in precipitation runoff suspended particles.

The military personnel MEI for inhalation exposure can be calculated as for the resuspended soil scenario for efficacy testing:

$1400\ mg/kg \times 0.250 \times 10^{-6}\ kg/M3 = 3.5 \times 10^{-3}\ mg/M^3$

This corresponds to a lifetime increased cancer risk of 2×10^{-4}, an order of magnitude below background radiation risk levels.

D.4.2 Combat-Related Health Risks

D.4.2.1 Tank Crew Radiation Exposures

Based on in-tank radiation from a half-filled DU kinetic penetrator ammunition rack measured at a location occupied by the tank crew member closest to the rack for one-quarter of a day, 7 days/wk, 52 weeks/yr, the maximum radiation exposure is on the order of .25 rem/yr, well below the occupational limit for the exposure of the extremities to DU radiation of 50 rem/yr. Using the cancer risk factors for extremities exposure cited above, the lifetime increased cancer risks associated with a 20 year exposure would be 5×10^{-6} and 2.5×10^{-5}.

When more realistic exposure scenarios are adopted, the health risks are further reduced.

D.4.2.2 Soldier Takes Refuge

Cole (1989) evaluated the chemical toxicity and radiation health risks associated with a soldier taking refuge in a disabled and abandoned enemy tank that had been struck by a chemical energy (explosive propulsion) DU penetrator. The maximum exposure calculated for such a combat scenario is 23 mrem, equivalent to a lifetime increased cancer risk of less than 5×10^{-6}. This is nearly three orders of magnitude less than the lifetime increased cancer risk calculated in the same manner resulting from all background radiation exposures.

D.4.2.3 Major Tank Battle

The largest tank battle recorded to date took place in the Arab-Israeli war of 1973, a 150-tank armor engagement. Using this as a unit of tank battle, the following assumptions are made to quantify exposures: 1) the largest penetrators are used (5 kg); 2) 25 percent of the penetrator is aerosolized on impact; 3) half of the penetrators reflect off the tank armor and the fragments are scattered over the 50 hectare battlefield; 4) 4 rounds are fired for every tank kill; 5) all tanks are killed; 6) all aerosolized DU settles on the 50 hectare battle field; 7) the soil is mixed to a depth of 0.005 M; and 8) the soil bulk density is 1.5×10^3 kg/M^3. The resulting maximum contaminant level at the soil surface is calculated to be 200 mg/kg, or about 100 times background levels. Until the first rainfall, the settled aerosol can be resuspended due to the movement of ground troops or ground vehicles. Assuming a maximum total suspended solids concentration of 0.25 mg/M^3, and a 24 hour exposure during two months of combat, then the lifetime increased cancer risk for military personnel in such a battle is 1.5×10^{-7}.

Assuming that the 200 mg/kg level does not decline with time (an impossible situation), the public living immediately downwind of such a battleground would experience a lifetime increased cancer risk from continuous inhalation exposure for a 70-year lifetime calculated as above of about 3×10^{-5}.

The quantity of fragments generated when the penetrators reflected off tank armor is:

5 kg/round x 4 rounds/tank x 150 tanks x 0.5 reflected x (1 - 0.25) unaerosolized = 1,125 kg DU fragments scattered over battlefield

The remaining 1,125 kilograms of fragments is assumed to solubilize at the rate of one percent per year, so that 11.25 kg of DU will be released to the surface soil layer each year, equivalent to a concentration of:

11.25 kg x 10^6 mg/kg / 50 hc x 10^4 M2/hc x 0.005 M x 1.5×10^3 kg/M3 = 3 mg/kg

D.4.3 Testing-Related Environmental Exposures

The same source term assumptions for open air accuracy testing apply as above. The resulting surface soil accumulation is 1400 mg/kg available for mobilization by wind resuspension or precipitation runoff.

D.4.3.1 Riverine Sediments

Assuming the area of the watershed in which the test range sits is about 10 km x 25 km or 2.5×10^8 M^2, and that the erosivity of the test range soil is roughly equal to that of other land areas in the watershed, the alluvial sediment particle dilution factor can be calculated as the ratio of the respective areas, or 3×10^{-3}. Multiplying 1400 mg/kg by this dilution factor yields the expected concentration of DU in the sediments of the nearby river of 4.2 mg/kg, or roughly three times background levels. If the stream is closer to the test range than the average parcel of land in the watershed, or if its intrinsic erosivity is greater than average, the dilution factor will decrease, and the corresponding concentrations in the sediment will increase.

However, as DU particles are unlikely to move as rapidly as other soil particles due to their higher densities, for DU particles that have not yet been solubilized, the accumulation may be localized at the point of confluence between the runoff area and the stream, with sediment concentrations declining rapidly thereafter. While significantly reducing the likelihood of exposure of the public, if exposure were to occur, it would be at correspondingly higher concentrations. If the point of confluence is within the perimeter of the military base, then public access to the most highly contaminated sediment will be precluded.

Due to the low levels of DU accumulated in the river, the calculation of the lifetime increased cancer risk to the barefoot wader has been foregone.

D.4.3.2 Testing-Related Groundwater Contamination

As stated above, the worst-case assumption is that the water table is just below the surface, resulting in an equilibration between the accumulated concentration in soil at the edge of the leaching horizon and the interstitial

pore water. For purposes of this analysis, the only measured soil:water partition coefficient for typical test site soils will be used: 4360 L/kg. The maximum concentration in interstitial pore water in equilibrium with the steady state DU soil value is 0.32 mg/kg.

If exposure occurred to the undiluted interstitial pore water, an individual drinking 2 L/day of such water for 70 years would be at an estimated lifetime increased cancer risk of 5×10^{-4}. This is roughly one-fourth the lifetime increased cancer risk from all natural background radiation sources. Nevertheless, it is above the 10^{-6} *de minimus* level adopted by several states to protect ground water quality.

While the actual concentration at the well head of the hypothetical drinking water well 5 km distance from the test site is likely to be far lower, the actual dilution afforded the leachate plume by an aquifer is so site-specific that it would serve little purpose to carry out a generic analysis here. However, for comparison purposes, the U.S. Environmental Protection Agency has used dilution factors as little as 6.3 fold for large area sources 500 feet from a generic drinking water well and 100-fold for large area sources at a long but unspecified distance from a municipal sewage sludge land application site.

Any concern that might arise over such potentially significant public health risks must be further tempered by the realization that at the rate of migration measured in surface soils at actual test sites, on the order of 0.005 M/yr, the effective soil:water distribution coefficient is probably one and perhaps two orders of magnitude greater than those measured in the laboratory for the Aberdeen site. That being the case, the risks of drinking undiluted contaminated soil interstitial soil pore water would decline proportionally.

D.5 PRELIMINARY CONCLUSIONS

Based on the above occupational, military non-combat and combat, and environmental exposure scenarios, the lifetime increased cancer risks to the MEI by inhalation of contaminated soil particles resuspended in air or consumption of contaminated drinking water will not exceed those associated with exposures

to background radiation levels from all sources. In many cases the lifetime increased cancer risks are below the 10^{-5} to 10^{-6} threshold that defines *de minimus* risk in several states.

Caveats to these preliminary conclusions are warranted, however. Contamination of sediments attributable to generic runoff from open air test ranges is not likely to result in accumulations significantly in excess of background levels when averaged over the entire stream, but localized accumulations significantly above background may occur. The likelihood of exposure to such accumulations will be minimized where they occur inside the periphery of the secured area, precluding public access. Contamination of groundwater in excess of the drinking water 10^{-6} risk level for DU-related radiation could occur if ordnance fragments are not collected after test shots, assuming a worst-case soil:water partition coefficient. When a more realistic soil:water partition coefficient is used, *de minimus* levels of concern are not likely to be exceeded.

Moreover, the time lag for the observation of excess DU contamination at a hypothetical drinking water well 5 km from the point of impact at a generic open air test range would be on the order of 10^4 to 10^6 years, if the same retardation factor were applicable in aquifer substrate as in soils. Nevertheless, should the chemistry of the anaerobic vadose zone or saturated zone be significantly different than that in the aerobic zone of the surface soil, more rapid DU transport cannot be precluded.

D.6 RECOMMENDATIONS

The uncertainties surrounding the source strength, transport and dilution of solubilized DU in soils and ground waters are sufficient that additional source-, species- and site-specific analyses of the conditions and phenomena governing migration of leachate off-site may be warranted.

APPENDIX E

BEIR V

Appendix A, "Cancer Mortality Risk Coefficient Update" provides a complete basis for the value of 3 x 10^{-4} cancer deaths per person-rem selected for this study. Since our draft report was prepared months prior to the publication of the National Research Council's BEIR V Report, it was logistically impossible to consider the new recommendations. Nevertheless, the BEIR V Report has since been thoroughly reviewed. It is the opinion of experts in the areas of risk assessment, radiation biology and health physics that there is no reason to change any of the risk estimates to incorporate the recommendations of the BEIR V Committee. Given the uncertainties inherent in such evaluations, technical experts generally agree that there is little real difference in current estimates of risk, including BEIR V.

As was true for the RERF and UNSCEAR 1988 Reports referenced in Appendix A, the new risk coefficients in BEIR V are based largely on the results of the re-evaluation of the doses and observed risks among the Japanese survivors of the Hiroshima and Nagasaki bombings that ended World War II. Since these studies share a common data base, it is understandable that many recommendations would be similar, even though the statistical methods employed to evaluate that common data base are not identical.

The major difference between estimates of risk by RERF and UNSCEAR versus BEIR V centers on the use of a dose rate effectiveness factor (DREF) to make an appropriate allowance for cellular repair mechanisms which have been observed in both cellular and animal studies of neoplastic transformations. The DREF factor is applied to risk estimates derived from epidemiologic studies of populations exposed to levels of radiation and dose rates that are many orders of magnitude greater than could ever be experienced by anyone exposed to DU under any conditions. The results of relevant animal studies are referenced in Table 1-4 (Summary of Dose-Rate Effectiveness Factors for Low-LET Radiation) of BEIR V. The DREF values for tumorigenesis were observed to range from 2 to 10 (as reported by UNSCEAR 1988, and noted at p. A-1 of Appendix A) with a single "best estimate" of 4. While the BEIR V Committee derived a DREF of 2.1 (vs 2.5 in the BEIR III Report) for leukemia, it declined to employ a DREF for all non-

leukemias. That decision has been questioned by many knowledgeable members of the radiation protection community, and Federal agencies are currently considering what appropriate actions may be called for in applying BEIR V recommendations to radiation protection standards in the U.S. and abroad.

In the interim, it is possible to reasonably speculate on the potential outcome of large-scale peer review of BEIR V recommendations. For example, it is reasonable to apply the BEIR V Committee's "best estimate" DREF of 4 to non-leukemias to see how that would impact the Committee's recommended value of 7.9×10^{-4} latent cancers per person-rem. If that were done, there would be no significant difference between that value and the value employed for this study (3×10^{-4}). If a DREF of 2 (the lower end of the range in BEIR V Table 2) were used to provide a risk coefficient for exposure to radiation given at low dose rates, the value would be about 4×10^{-4}. That is not significantly different from the value employed in this report, given the current uncertainties in both dose and risk assessment associated with exposures to DU. Finally, cognizance of the DREF of 2.5 currently preferred by RERF scientists most familiar with the A-bomb survivors is explicitly noted in Appendix A (p. A-1).[a]

However, it should also be noted that for the dose rates and potential doses to exposed personnel which might reasonably accrue from worst case battlefield conditions (much less than a rem), the actual radiation risk could be zero. As noted by <u>every</u> BEIR Committee since BEIR I (1972), the risk from exposures comparable to external natural background radiation may not be different from zero (see also p. 181 of BEIR V).

---

[a] The International Commission on Radiological Protection (ICRP) has prepared draft "Recommendations of the Commission - 1990" which also examined the question of DREF (see pp. B-19 through B-20, and B-42 through B-43 of the draft), and concluded that the appropriate value was 2 for occupational exposures (which would be much higher than might reasonably result for DU under worst-case battlefield conditions or under current occupational conditions for manufacture of KE penetrators).

APPENDIX F

Potential Radiation Doses Associated With The Battlefield Use of Depleted Uranium Munitions

NOTE: This appendix has been added to the risk assessment for informational purposes only. The authors of the risk assessment have not explicitly incorporated this paper's findings into the rest of the document. This paper constitutes only a preliminary assessment of some of the issues involved in potential battlefield radiation doses.

POTENTIAL RADIATION DOSES ASSOCIATED WITH THE BATTLEFIELD USE OF DEPLETED URANIUM MUNITIONS

This paper provides a brief assessment of the potential radiation doses associated with the battlefield use of depleted uranium (DU) munitions. This assessment is based on an extrapolation of information from studies performed in 1983 and 1985 by Battelle's Pacific Northwest Laboratories, for the Department of the Army, Large Caliber Weapons Systems Laboratory. It is important to realize, however, that the studies referenced are not entirely applicable to battlefield conditions. They provide data for a penetrator oxidized slowly as compared to the battlefield conditions when a penetrator would be oxidized promptly. This difference in rate and conditions of oxidation of the penetrator limits the validity of the comparison.

The most recent Battelle study was published as PNL-5928 (Hazard Classification Test of the 120-mm, APFSDS-T, M829 Cartridge: Metal Shipping Container). PNL-5415 (Potential Behavior of Depleted Uranium Penetrators under Shipping and Bulk Storage Accident Conditions) provides a summary of burn test data obtained on DU munitions studies through 1985.

Although other studies were performed on other types of munitions in various shipping containers and configurations, the 1985 study provided the most complete assessment of the amount and percentage of DU oxidized, percentage of DU oxide not recovered (and assumed to be released as an airborne contaminant), characterization of the DU oxide with respect to solubility and particle size, and both computer projections and actual measurements of downwind air concentration and ground deposition.

VALIDITY OF COMPARISON

Both studies consisted of exposing twelve (12) complete munitions rounds packed tightly together in a very hot fire to simulate a potential transportation accident. The heat from the fire caused portions of the DU penetrators to oxidize slowly into DU powder (U_3O_8) whose physical, chemical, radiological, and toxicological properties were characterized thoroughly as

described in PNL-5928. Further details on the various compounds and particle sizes formed under simulated accident conditions can be found in PNL-5415.

In a battlefield situation, where DU penetrators are oxidized promptly upon impact with hard targets, the resulting materials can have significantly different physical, chemical, and morphological properties. This can occur because the DU material is in intimate contact with various target materials during the sudden, violent transformation of kinetic energy to heat energy. This release of heat energy can create different chemical compounds or products other than those that were formed during slow oxidation as occurred in the test cases when the DU was in contact with air only.

A study published in 1979 (PNL-2944, Characterization of Airborne Uranium from Tests Firings of XM 774 Ammunition) provides more details of the resulting products formed as a result of DU penetrator impacts on hard targets. Although air sampling was performed during the impact tests, the samples were taken within a few feet of the targets and the researchers provided no dose assessments resulting from possible inhalation scenarios. For this paper, however, the study did show that particle size and solubility could be different than that determined in the burn tests.

DISCUSSION

For the battlefield scenario, the potential for the greatest dose to non-combatants probably exists from inhalation of the respirable portion of the DU as an airborne oxide. The external radiation dose from a single oxidized penetrator source that has been diffused after impact can be considered insignificant under most reasonable exposure scenarios. Typical external dose rates of intact penetrators in various configurations can be found in PNL-5927 (Radiological Assessment Test of the 120-MM APFSDS-T M829 Cartridge: Metal Shipping Container).

The mass of DU metal oxidized in the 1985 test (4 kg +/- 10%) can be used to approximate the mass of metal that would be involved in the total oxidation of one large-caliber penetrator upon impact with a hard target.

Assuming physical and chemical properties remain similar, the data obtained from the 1985 test can be considered valid for one hard-target impact of a DU penetrator. This mass can be scaled as appropriate for various battlefield scenarios.

In that test, the computer code DUDOSE predicted a maximum downwind, time-dependant concentration of 1E-3 mg-h/m^3 at 100 meters downwind distance using conservative meteorology. This concentration relates to a deposition of 12 ug on an air filter for the duration of the test assuming an air sample rate of 35 m^3/h. Using a breathing rate representative of rigorous exercise of 2.4 m^3/h, the total mass deposited in the body is 0.82 ug, which equates to an activity of 3.3E-7 uCi. The corresponding radiation dose associated with this deposition and activity is projected to be 0.04 mrem effective dose equivalent (ede) for each penetrator that is completely oxidized. This estimate is calculated using the dose conversion factor of 120 rem/uCi for Y-class Uranium-238 deposited in the body as listed in DOE/EH-0071.

Although DUDOSE computer estimates predicted test concentrations that could result in an effective dose equivalent of 0.04 mrem per penetrator, the code contains very conservative assumptions and the projected dose could be a significant over-estimate. In reality, no positive airborne results were confirmed by air sampling or on the deposition trays during any of the hazard classification tests.

For toxicological purposes, the kidney is the critical organ with a chronic and acute (30 minutes) exposure limits of 0.2 mg/m^3 and a 20 mg/m^3, respectively. These concentrations would not be expected in a battlefield situation without an extremely large number of penetrators being oxidized. The hard impact test results published in 1979 indicated that these concentrations could be achieved, at least temporarily, in the immediate area of impact. The researchers hinted at a possible toxicological hazard, however, this possibility was not pursued.

The 0.04 mrem/penetrator effective dose equivalent figure can be used as a reference to calculate radiation doses for any potential battlefield

scenario involving large-caliber penetrators. Smaller caliber munitions (e.g. M919) can be included in projections on a per mass basis; that is, considering the ratio of the total DU mass in the M919s and the mass associated with one large caliber penetrator. Dose estimates for the battlefield destruction of 1, 10, and 100 large caliber DU penetrators are listed in Table 1.

Table 1. Projected Effective Dose Equivalent Resulting From Oxidation of Depleted Uranium Penetrators

Number of Penetrators Oxidized	mrem Effective Dose Equivalent
1	0.04
10	0.4
100	4

It should be noted that the doses are derived from a projected maximum downwind concentration of contaminants originating from a point source. Actual concentrations could be considerably less as demonstrated previously. In addition, diffused sources, typical of a battlefield situation, could further reduce the magnitude of maximum downwind concentrations at single locations.

OTHER PERTINENT INFORMATION

The information presented in Table 2 was obtained during the hazard classification tests of the DU penetrator rounds. Additional information that could be useful in further evaluating the consequences of using DU penetrator munitions include:

- DU Oxide particles must be <20 um AED to be transported by wind;
- DU Oxide particles must be <10 um AED to be an inhalation hazard;
- No test air sampler (placed 56 to 187 meters from ground zero) recorded a positive result.

CONCLUSIONS

The single oxidized penetrator radiation dose of 0.04 mrem effective dose equivalent from the internal deposition of material represents an insignificant risk to non-combat personnel. The risk would, however, increase in proportion to the number of penetrators destroyed on the battlefield. External radiation doses, although considered insignificant here for a few penetrators, may become significant as DU material accumulates in limited battlefield areas.

Table 2. Test Data for 1983 and 1985

PARAMETER	1983 TEST	1985 TEST
DU Recovered	100%	99.4 +/- 1.8%
Penetrator Oxidation	84%	9.5%
Mass DU Oxidized	NA	4.553 kg
Predominant Oxide	UO_2 (not confirmed)	U_3O_8
Percent of DU Oxide with Particle Size <10um AED	0.2-0.6%	0.07%
Solubility Classification	100% Y class	96% Y class 4% D class
Highest Downwind Conc. (Calculated)	NA	1E-3 mg-h/m^3
Highest Downwind Conc. (Measured)	NA	0.0

AED - Aerodynamic Equivalent Diameter

REFERENCES

Glissmeyer, J. A., Mishima, J., Characterization of Airborne Uranium From Test Firings of XM774 Ammunition, PNL-2944, 1979.

Haggard, D.L., et. al., Hazard Classification Test of the 120-MM, APFSDS-T, M829 Cartridge; Metal Shipping Container, PNL-5028, 1986.

Hooker, C.D., Hadlock, D.E., Radiological Assessment Test of the 120-MM, APFSDS-T, M829 Cartridge; Metal Shipping Container, PNL-5927, 1986.

Mishima, J., et. al., Potential Behavior of Depleted Uranium Penetrators under Shipping and Bulk Storage Accident Conditions, PNL-5415, 1985.

U.S. Department of Energy, Internal Dose Conversation Factors for Calculation of Dose to the Public, Publication DOE/EH-0071, 1988.